Series II, Volume 4 December 28, 1959 Number 8

BULLETIN

OF THE

AMERICAN PHYSICAL SOCIETY

INCLUDING THE

PROGRAMME OF THE

1959 WINTER MEETING IN THE WEST

AT THE

CALIFORNIA INSTITUTE OF TECHNOLOGY, PASADENA

December 28–30, 1959

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December 28, 1959 Series II, Vol. 4, No. 8

BULLETIN

OF THE

AMERICAN PHYSICAL SOCIETY

1959 Winter Meeting in the West, California Institute of Technology, Pasadena
December 28–30, 1959

THE 1959 **Winter Meeting in the West** will be held at the California Institute of Technology, Pasadena, California, on Monday, Tuesday, and Wednesday, December 28, 29, and 30, 1959. The sessions will be held in Culbertson Hall, Bridge Laboratory, the Arms Laboratory, and Kerckhoff Laboratory, all on campus. The McKinley Junior High School Auditorium at 325 South Oak Knoll, a fifteen-minute walk from Bridge Laboratory of Physics, has been reserved for the session on the Detection of Nuclear Explosions which will take place on Tuesday afternoon. Registration will be just outside Bridge Laboratory and there will be the usual telephone and message service and conference rooms will be nearby.

The **hotel situation** is extremely difficult because of the opening of the Santa Anita Race Track season and the Rose Bowl Game, and it has been impossible for the Local Committee to get blocks of rooms at the local hotels and motels in Pasadena. Despite this difficulty, it is recommended that individual members desiring nearby accommodations try to make their own reservations. It is simply that blocks of space were unavailable. The Local Committee was successful, however, in having a block of rooms set aside at the Statler Hotel in downtown Los Angeles. The Statler is a fine hotel and has offered to take reservations for members of the American Physical Society who are attending the meeting providing the reservations are made in reasonable time before the meeting. Taxi fare from the Hotel Statler to the Institute will be $5.00 but can be shared by as many as four people. For others, the Local Committee is arranging for bus transportation to take members of the Society from the Statler Hotel to the campus and back again.

Luncheon accommodations will be available at the Athenaeum and the Coffee Shop. The Coffee Shop itself is being reserved for members of the American Physical Society after 12:30 P.M.

Registration, including information on accommodations, the banquet, the cocktail party, side trips, and other information will be at desks in the patio area outside of Bridge Laboratory. There will be a registration fee of $1.00. Professor Ward Whaling is the Chairman of the Local Committee, and all requests about local problems should be addressed directly to him, care of the Physics Department, California Institute of Technology.

Tickets for the **banquet** of the Society will be sold at the registration desk. The price is $4.50 per person and the dinner will be held at 7:30 P.M., Tuesday evening, at the Huntington-Sheraton Hotel in Pasadena. We must remind members who plan to go to the banquet that they should purchase their tickets as soon as possible, because recent dinners have been over-subscribed, and some members have been unable to attend who wanted to do so. This will be a problem all the more so, since our principal speaker will be Professor R. P. Feynman, of the California Institute of Technology, and the title of his talk will be "There's Plenty of Room at the Bottom." Professor Uhlenbeck, President of the Society, will be the presiding officer.

A **prize** endowed by Hughes Aircraft Company will be awarded (for the first time) at the banquet. More information about this endowment will be published in a later issue of this Bulletin.

The program consists of **113 contributed papers** and **44 invited papers.** The program was arranged with the aid of a committee consisting of Professors W. Whaling, N. Oleson, T. Lauritsen, J. R. Pellam, J. G. Bolton, W. A. Fowler, H. V. Neher, A. R. Hibbs, and Dr. H. Brown. A special feature of the program is Session K, on Tuesday afternoon, on the Detection of Nuclear Explosions. It was because of the anticipated, general interest that the larger auditorium of the local Junior High School was retained for this session.

Post-deadline papers of sufficient importance to warrant their inclusion in a special supplementary program will be considered by the Local Secretary if the abstracts are received no later than Friday, December 18, at the Office of the Local Secretary for the Pacific Coast (see address below). These papers will be presented following sessions that will be designated on a blackboard near the registration desk outside of Bridge Laboratory.

Errata will be published in a later issue of this Bulletin if received not later than Monday, January 4, at the office of Miss Ruth Bryans, American Institute of Physics, 335 East 45th Street, New York 17, New York. Do not send your abstract defaced with corrections: write out the corrections in the form "Instead of . . . read. . . ." Do not add anything. Errata are not published either for introducing new data, or for restoring material that was cut out because the abstract was too long.

W. A. NIERENBERG,
Local Secretary for the Pacific Coast
Department of Physics
University of California
Berkeley 4, California

EPITOME OF THE 1959 WINTER MEETING IN THE WEST AT THE CALIFORNIA INSTITUTE OF TECHNOLOGY

(Personal names are those of invited speakers.)

Monday Morning

10:00 A. Radio astronomy; Roberts, Minkowski, Hoyle, Schmidt. Culbertson Hall.

10:00 B. Low-temperature physics; Tinkham, Fairbank, Mercereau, Koehler. Bridge 201.

10:00 C. Low-energy nuclear physics I. Arms 155.

Monday Afternoon

2:00 D. Age of the elements and astrophysical systems; Fowler, Wasserburg, Wilson, Greenstein, Sandage. Culbertson Hall.

2:00 E. Division of electron physics; Rosen, Aller, Ecker, Cronin. Arms 155.

2:00 F. High-energy nuclear physics. Bridge 201.

2:00 G. Plasma physics and cosmic rays. Kerckhoff 119.

Tuesday Morning

9:30 H. High-energy nuclear physics; Perez-Mendez, Solmitz, Chew, Olbert, Schein. Culbertson Hall.

9:00 I. Resonance and solid state physics; Crane. Bridge 201.

9:30 J. Electron physics and spectroscopy. Arms 155.

Tuesday Afternoon

2:00 K. Detection of nuclear explosions; Brown, Romney, Press, Martinelli, Latter. McKinley Junior High School Auditorium.

Tuesday Evening

7:30 Banquet of the American Physical Society; Feynman. Huntington-Sheraton Hotel.

Wednesday Morning

9:30 L. Space physics; Gold, Snyder, Urey, Sonett, Simpson. Culbertson Hall.

9:30 M. Low-energy nuclear physics; Bonner, Fowler, Lidofsky, Gove. Bridge 201.

9:00 N. Solid-state detectors and solid-state physics; Mayer. Arms 155.

Wednesday Afternoon

1:45 O. Solar cosmic rays; Leinbach, Winckler, Ney, Meyer, Davis. Culbertson Hall.

1:45 P. Low-energy nuclear physics II. Bridge 201.

1:45 Q. Resonance and solid-state physics II. Arms 155.

PROGRAMME

MONDAY MORNING AT 10:00

Culbertson Hall

(J. G. BOLTON presiding)

Invited Papers on Radio Astronomy

A1. Solar Disturbances in the Radio Spectrum. J. A. ROBERTS, *California Institute of Technology.* (30 min.)

A2. Identification of Radio Stars. R. L. MINKOWSKI, *Mt. Wilson and Palomar Observatories.* (30 min.)

A3. Mechanism of Radio Emission. F. HOYLE, *Cambridge University, and California Institute of Technology.* (30 min.)

A4. Twenty-One Centimeter Radiation and the Structure of the Galaxy. M. SCHMIDT, *California Institute of Technology.* (30 min.)

MONDAY MORNING AT 10:00

Bridge 201

(J. R. PELLAM presiding)

Invited Papers on Low-Temperature Physics

B1. Energy Gap in Superconductors. M. TINKHAM, *University of California, Berkeley.* (30 min.)

B2. Nuclear Resonance Measurements in Liquid and Solid Helium 3. W. FAIRBANK, *Stanford University.* (30 min.)

B3. Second Sound Diffraction in Stationary and Rotating Liquid Helium II. J. MERCEREAU, *California Institute of Technology.* (30 min.)

B4. Investigations on the Hydrodynamics of Superflow. T. KOEHLER, *California Institute of Technology.* (30 min.)

MONDAY MORNING AT 10:00

155 Arms

(C. A. BARNES presiding)

Contributed Papers on Low-Energy Nuclear Physics I

C1. $T(p,n)He^3$ Reaction and Its Inverse.* JOHN D. SEAGRAVE, *Los Alamos Scientific Laboratory.*—Recent experimental work on this important neutron-source reaction will be reviewed. Unpublished work at LASL which has been analyzed includes the experimental determinations by J. E. Perry *et al.*[1] of the absolute forward yield measured with a counter telescope for E_p between 2 and 7.5 Mev, and complete relative angular distributions, measured with a "long counter," for E_p between 1.5 and 5.5 Mev. The detailed sensitivity of the long counter was measured using the forward yield. The angular distributions have been normalized to the forward yield, converted to the c.m. system, and fitted with series of Legendre polynomials by a weighted least-squares process. The results have a smooth energy dependence and exhibit a pronounced increase in backscattering with increasing energy. The integrated reaction cross sections are in good agreement with work at Oak Ridge using a thermalizing integral method. The $T(p,n)He^3$ cross sections have also been converted to the inverse $He^3(n,p)T$ case. All available direct measurements, though less precise, give somewhat lower cross sections than those calculated from detailed balancing. The implications of the strong $He^3(n,p)T$ reaction and the weaker $He^3(n,d)D$ reaction for analysis of n-He^3 elastic scattering will be discussed.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

[1] The participants in this work were J. E. Perry, Jr., E. Haddad, R. L. Henkel, G. A. Jarvis, and R. K. Smith.

C2. Investigation of the $He^3(p,\gamma)Li^4$ Reaction.* P. D. PARKER, S. BASHKIN,† AND R. W. KAVANAGH, *California Institute of Technology.*—Because of recent interest in the possibility of the stability of Li^4 against heavy particle emission, and the effects that such stability would have on the rate of hydrogen burning in stars, the reaction $He^3(p,\gamma)Li^4$ was studied by looking for delayed positron activity in a gas target with a well-type plastic scintillator. The accelerated proton beam was chopped magnetically at 120 cps and the

scalers gated synchronously. The detection efficiency for the expected 19-Mev positrons was determined to be 80%. An upper limit on the cross section for the formation of heavy-particle-stable Li^4 by this reaction was found to be 4.5×10^{-31} barn for a positron decay mean-life between 6 msec and 600 sec.

* Supported in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
† On leave from the State University of Iowa. Now at School for Physical Sciences, Australia National University, Canberra.

C3. Neutrons from the Proton Bombardment of Li^6 and Li^7.* F. AJZENBERG-SELOVE AND C. F. OSGOOD, *Haverford College*, AND C. P. BAKER, *Brookhaven National Laboratory.*—The $Li^7(p,n)Be^7$ and $Li^6(p,n)Be^6$ reactions have been studied at $E_p=10.5$ Mev, by the method of proton recoils in nuclear emulsions. The $Li^7(p,n)Be^7$ spectra at 30° and 90° show the known states of Be^7 at 0, 0.43, and 4.53 Mev. The cross section for formation of the ground state at 90° (lab) is 3.2 mb/sterad (±30%). The $Li^6(p,n)Be^6$ spectra at 30°, 60°, 90°, and 135° show ground-state groups with $Q=-5.05\pm0.2$ Mev. This leads to $(M\text{-}A)$ for $Be^6=20.13\pm0.2$ Mev. $Be^6(0)$ is thus unbound with respect to (He^4+2p) by 1.35 Mev. The cross section for formation of $Be^6(0)$ at 90° (lab) is 0.5 mb/sterad (±30%). At 90°, there is also indication of a sharp excited state at $E_p=1.5\pm0.2$ Mev. The lifetimes of $Be^6(0)$ and $Be^6(1.5)$ are $\gtrsim4\times10^{-21}$ sec and $>7\times10^{-21}$ sec, respectively. These results are discussed in terms of the other available information on the $A=6$ isobars.[1]

* Work supported by the National Science Foundation and the U. S. Atomic Energy Commission.
[1] Bogdanov, Vlasov, Kalinin, Rybakov, and Sidorov, Soviet J. Atomic Energy 3, 987 (1957); F. Ajzenberg-Selove and T. Lauritsen, Nuclear Phys. 11, 1 (1959).

C4. $Be^7(p,\gamma)B^8$ and $Be^7(d,p)Be^8$ Cross-Section Measurements.* R. W. KAVANAGH, *California Institute of Technology.*—The cross section for production of B^8 from proton bombardment of Be^7 is found to be 0.48 ± 0.18 microbarn and 0.50 ± 0.20 microbarn at 800- and 1400-kev proton energy, respectively. Extrapolation to stellar thermal energy indicates a cross-section factor $S_0=0.02$ kev-barn. The yield of proton groups from $Be^7(d,p)Be^8$ shows two resonances in the range 0.7- to 1.7-Mev deuteron energy, at 0.90 and 1.475 Mev, with widths $\Gamma_{cm}=120\pm40$ and 71 ± 8 kev respectively, corresponding to excited states at 17.2 and 17.62 Mev in B^9. No groups attributable to Be^8 are seen except those corresponding to the ground state (p_0) and first excited state (p_1), along with a continuum extending to beyond 11-Mev excitation. Only p_1 is resonant at 1.475 Mev. The excitation and width of the first excited state are found to be $E_x=2.96\pm0.03$ Mev and $\Gamma=1.53\pm0.04$ Mev.

* Supported in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

C5. Elastic Scattering of Protons by B^{10} from 150 to 650 kev.* J. C. OVERLEY, *California Institute of Technology.*—Protons elastically scattered from B^{10} have been studied in the energy range from 150 to 650 kev. Targets were prepared by thermally decomposing diborane (B_2H_6) enriched to 96% B^{10} and were analyzed for impurities by elastic proton scattering. Excitation functions were obtained at $\theta_{cm}=90°$, 125°16′, and 162°, and angular distributions were taken at 10° intervals from $\theta_{cm}=90°$ to 160° at proton energies of 200, 300, 400, 500, and 600 kev. At 162° the ratio of the observed scattering cross section to the Rutherford cross section rises smoothly from unity at 150 kev to 1.56 at 650 kev. No resonant scattering corresponding to previously reported levels in C^{11} at excitation energies of 8.98, 9.13, and 9.28 Mev was observed. The data are consistent with pure s-wave potential scattering assuming equal potential scattering phase shifts in the 7/2 and 5/2 channels.

* Supported in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

C6. Gamma Rays from Medium Energy Proton Bombardment of Carbon. R. E. SEGEL,* A. B. CLEGG, G. L. SALMON, AND K. J. FOLEY, *Clarendon Laboratory, Oxford.*—The gamma-ray spectrum from the bombardment of 20-Mev thick carbon targets with 70–150 Mev protons from the Harwell 110 in.-cyclotron has been measured using a 6 in.×5 in. NaI(Tl) crystal. The gamma-ray production cross section was measured by comparison with the known cross section for producing C^{11}. The following table lists the gamma rays observed, together with their parent state and production cross section at 150 Mev:

E_γ(Mev)	Parent state		$\sigma(mB)$
0.72	B^{10}	0.72	1.5
1.02	B^{10}	1.74	0.7
1.99	C^{11}	1.99	1.0
2.11	B^{11}	2.11	0.25
4.43	C^{12}	4.43	4.4
15.1	C^{12}	15.1	0.1

The production cross section for the 4.43-Mev gamma ray varies approximately as $1/E$, while that for the C^{11} 1.99-Mev gamma ray decreases more slowly with increasing energy.

* Permanent address: Aeronautical Research Laboratory, Dayton, Ohio.

C7. Angular Correlation in Proton Inelastic Scattering from Carbon at 150 Mev. A. B. CLEGG, K. J. FOLEY, G. L. SALMON, AND R. E. SEGEL,* *Clarendon Laboratory, Oxford.*—The angular correlation of recoil proton and gamma ray from inelastic scattering of 150-Mev unpolarized protons from the 4.43-Mev state of C^{12} has been measured. The proton counter was at a fixed angle and the gamma-ray counter was moved to various angles in the plane determined by the incoming and outgoing protons. For proton angle $\theta_p=35°$ the angular correlation is of the form $A+B\sin^2(\theta_\gamma-\theta_R)$ where θ_γ is the gamma-ray angle and θ_R is the angle of the recoil nucleus. A/B is approximately 0.3. This work was done on the Harwell 110-in. cyclotron.

* Permanent address: Aeronautical Research Laboratory, Dayton, Ohio.

C8. $N^{14}(d,n)O^{15}$ Excitation Curves and Angular Distributions.* JESSE L. WEIL AND THEO RETZ-SCHMIDT, *The Rice Institute.*—The excitation curve for $N^{14}(d,n)O^{15}$ has been measured at 0° from 0.70 to 5.70 Mev in 40-kev steps using a pulse shape discrimination detector to eliminate the γ-ray background. Many narrow resonances were observed. The cross sections agree well with previous measurements.[1] The excitation curves at 30°, 90°, and 164° have also been measured in 100-kev steps. Angular distributions have been measured at 0.88, 1.17, 1.55, 1.94, 2.65, 3.13, 3.44, 4.27, and 4.80 Mev. The angular distribution at 1.94 Mev is in good agreement with a previous measurement by Nonaka *et al.*[2] Several of the angular distributions are most strongly peaked in the backward direction. A curve of pulse-height *versus* recoil proton energy for stilbene will also be shown.

* Supported in part by the U. S. Atomic Energy Commission.
[1] J. L. Weil and K. W. Jones, Phys. Rev. 112, 1975 (1958).
[2] Nonaka, Morita, Kawai, Ishimatsu, Takeshita, Nakajima, and Takano, J. Phys. Soc. Japan 12, 841 (1957).

C9. $O^{16}(He^3,n)Ne^{18}$ Reaction. K. L. DUNNING AND J. W. BUTLER, *U. S. Naval Research Laboratory.*—Thin targets of O^{16} were bombarded with singly charged He^3 ions in the energy range 3.4 to 5.6 Mev. The neutrons were observed by means of the counter-ratio method. The ground-state neutron threshold was determined to be 3.811 ± 0.015 Mev corresponding to a Q value of -3.206 ± 0.013 Mev and to a mass of 18.011444 ± 0.000015 amu for Ne^{18}. An increase in slow

neutron counts appeared as the bombarding energy exceeded 3.947 ± 0.015 Mev. If this were taken as evidence for an excited state in Ne^{18}, this state would lie 0.114 ± 0.015 Mev above the ground state. These data are based upon Wapstra's mass tables.[1] The half-life of Ne^{19} was determined to be 1.25 ± 0.20 sec from observations of the annihilation radiation due to the positrons from the decay of Ne^{19}. A sodium iodide scintillator was used in conjunction with a single-channel and a 100-channel pulse-height analyzer. The positron scaler was photographed with a motion picture camera simultaneously with a scaler counting the 60 cps from a commercial line.

[1] A. L. Wapstra, Physica **21**, 367 (1955).

C10. The 4.24-Mev Level in Mg^{24}. R. Batchelor, A. J. Ferguson, H. E. Gove, and A. E. Litherland, *Chalk River Laboratories.*—The reaction $Mg^{24}(pp'\gamma\gamma)Mg^{24}$, using the Chalk River tandem accelerator, has been employed to study the level in Mg^{24} at 4.24 Mev. Double correlations and triple correlations in two different geometries of the gamma rays from this level sufficed to unambiguously establish its total angular momentum as 2. In the theoretical interpretation of these triple correlations, in which the inelastic proton is unobserved, the coefficients for $(P_{\gamma\gamma})$ correlations tabulated by Ferguson and Rutledge[1] are used directly.[2] The branching ratio of the gamma rays from the 4.24-Mev level to the ground and 1.37-Mev states has been measured to be 2.9 ± 0.5 and the $E2$ to $M1$ amplitude ratio for the first member of the stopover transition is found to lie between 10 and 40. These data give qualitative support to the collective model but there are quantitative disagreements with the detailed predictions for both spheroidal and triaxial ellipsoidal nuclei.[3]

[1] A. J. Ferguson and A. R. Rutledge, Chalk River Report CRP 615 February, 1957 (unpublished).
[2] A. E. Litherland and A. J. Ferguson (to be published).
[3] A. S. Davydov and G. F. Filippov, Nuclear Phys. **8**, 237 (1958).

C11. $(p,p'\gamma)$ Angular Correlations at Low Energy.* H. J. Hausman, G. F. Dell, and H. F. Bowsher, *The Ohio State University.*—At an incident proton bombarding energy of 6.5 Mev, angular correlations have been measured between protons scattered inelastically from various even-even nuclei and the decay gamma rays from the first excited states of these nuclei. Among the angular correlation experiments reported are $C^{12}(p,p'\gamma)4.4$ Mev, $Ne^{20}(p,p'\gamma)1.63$ Mev, $Si^{28}(p,p'\gamma)1.78$ Mev, and $S^{32}(p,p'\gamma)2.25$ Mev, which were done for proton detector angles of 60°, 90°, and 120°. The measured angular correlation functions are all of the form $A+B\sin^2(\theta-\theta_0)$ where θ_0 is the axis of symmetry. None of the symmetry directions agreed with predictions of the simple direct-reaction theories. However, the symmetry directions for correlation functions changed with proton detector angle for the experiments on C^{12}, Ne^{20}, and S^{32}; for the experiment on Si^{28} the correlation functions were symmetric about 90° independent of proton detector angle. The results of the angular correlation experiments appear to be consistent with a collective interaction involved in these direct-type reactions rather than a nucleon-nucleon type collision at the nuclear surface.

* Supported in part by the U. S. Atomic Energy Commission.

C12. Elastic and Inelastic Scattering from Mg.* D. K. McDaniels, G. W. Farwell, and J. S. Blair, *University of Washington.*—According to the mechanism of strong absorption diffraction scattering, both elastic and inelastic differential cross sections should be the product of two factors, one proportional to k^2, the other involving oscillating functions of the argument $2kR_0\sin(\theta/2)$. To study the k dependence, elastic and 1.37-Mev inelastic cross sections for Mg^{24} have been measured for alpha particles with 41-, 34-, and 29-Mev incident energy and for deuterons of 21-Mev energy. These and other previously measured cross sections have been divided by k^2 and then plotted *versus* $2k\sin\theta/2$. The alpha-particle results are approximated by "universal" curves which are compared to theory.

* Supported in part by the U. S. Atomic Energy Commission.

C13. Scattering of Alpha Particles and Deuterons by Iodine-127. I. J. Van Heerden,* *Nuclear Physics Division of the National Physical Research Laboratory, C.S.I.R., Pretoria, South Africa,* and D. J. Prowse, *University of California, Los Angeles* (introduced by J. R. Richardson).—The differential elastic scattering cross sections of 38-Mev α particles as well as 8- and 19.5-Mev deuterons by I^{127} have been determined using nuclear emulsions. The angular distributions obtained have been analyzed according to Porter's model of absorption along classical undistorted Coulomb orbits. Information is thus obtained on the mean free path of the incident particles in nuclear matter. In the course of this experimental work, indications of the existence of a Cohen peak in the inelastic scattering have been observed; the evidence will be described and the implications discussed.

* Present address: National Research Council, Ottawa, Canada.

C14. Range of Heavy Ions in Solid Materials.* Darden Powers, *California Institute of Technology.*—The range of N, Ne, and A ions in Be and C has been investigated for incident ion energy in the region 50–500 kev. A monoenergetic ion beam accelerated in the 600-kev electrostatic accelerator strikes a thick target of the stopping material, and the depth of penetration of the ions into the target is determined by a momentum analysis of monoenergetic protons scattered elastically from the target and from the atoms imbedded in the target. The value of dE/dX for argon ions in the energy range 50–500 kev is found to be constant in accord with a theory due to Bohr of the energy loss of neutral atoms. In both C and Be the value of the constant dE/dX for A-ions falls 30% above the theoretical value. For N and Ne ions dE/dX increases with ion velocity as would be expected from an increase in the effective charge of the moving ion.

* Supported in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

C15. Effects of Altering Shielding Materials and Detectors within a Long Counter on Neutron Flux Measurements. E. Tochilin and R. V. Alves, *U. S. Naval Radiological Defense Laboratory.*—Long-counter response to neutrons from a 2-Mev positive ion accelerator was investigated with three instruments, identical except for the thermal shields within the outer core. These consisted of B_2O_3, Cd and polyethylene sleeves. For neutrons from 0.1 to 4 Mev no differences in relative response were observed for the three counters. Influence of the three materials on neutrons reaching the detector from the outer paraffin shield was determined by shielding the central core with a shadow cone. Measurements at 0.4, 1.2, and 4.1 Mev and with PuBe neutrons also were made with indium and gold strips placed along the axis of the counter in place of the conventional BF_3 counter. These results indicate that foils can be substituted for the BF_3 detector with no sacrifice in energy response. The foil technique is of value wherever high intensity or pulsed neutron beams preclude the use of proportional counting.

C16. Neutron Excitation Functions, 7-14 Mev.* H. A. Tewes, A. A. Caretto, and A. E. Miller, *Lawrence Radiation Laboratory, Livermore.*—Excitation functions for the $(n,2n)$ reaction have been determined on the target nuclides Y^{89}, Nb^{93}, Rh^{103}, Ag^{107}, Sn^{112}, Au^{197}, and Th^{232}, as have the (n,p), (n,α), and (n,n') cross sections for some of these nuclei. The source of monoenergetic neutrons was a deuterium gas

target bombarded by deuterons from the Livermore variable-energy cyclotron. A proton recoil counter telescope was used to monitor the monoenergetic neutrons from the $D(d,n)He^3$ reaction and to enable appropriate corrections to be made for the spectrum of neutrons produced by the $D(d,np)D$ reaction. The total inelastic cross sections of a number of the target nuclides studied have been calculated using the statistical model,[1] and experimental results are compared with theory. In all cases, it will be seen that at the higher energies, the $(n,2n)$ process is predominately responsible for the observed inelastic cross section.

* This work was performed under the auspices of the U. S. Atomic Energy Commission.

[1] J. M. Blatt and V. F. Weisskopf, *Theoretical Nuclear Physics* (John Wiley & Sons, New York, 1952), Chap. VIII.

MONDAY AFTERNOON AT 2:00

Culbertson Hall

(F. HOYLE presiding)

Invited Papers on the Age of the Elements and Astrophysical Systems

D1. Age of the Elements. W. A. FOWLER, *California Institute of Technology.* (20 min.)

D2. Age Determinations of Meteorites and the Earth. G. J. WASSERBURG, *California Institute of Technology.* (20 min.)

D3. Age of Nearby Stars. O. C. WILSON, *Mt. Wilson and Palomar Observatories and California Institute of Technology.* (25 min.)

D4. Age of White Dwarf Stars. J. L. GREENSTEIN, *Mt. Wilson and Palomar Observatories, and California Institute of Technology.* (20 min.)

D5. Age of the Galaxy and the Universe. A. SANDAGE, *Mt. Wilson and Palomar Observatories.* (30 min.)

MONDAY AFTERNOON AT 2:00

Arms 155

(W. B. KUNKEL presiding)

Invited Papers on Electron Physics

E1. Results of Ionizing Radiation Experiments on Earth Sattellites. A. ROSEN, *Space Technology Laboratories.* (30 min.)

E2. Collisional Excitation of Spectral Lines in the Astronomical Range of Energies. L. H. ALLER, *Observatory of the University of Michigan.* (30 min.)

E3. Theory of the Electrode Regions of High-Current Arcs. G. ECKER, *Bonn University and the U. S. Naval Postgraduate School.* (30 min.)

E4. Recent Developments in Thermionic Cathodes. L. J. CRONIN, *Semicon of California, Inc.* (30 min.)

MONDAY AFTERNOON AT 2:00

Bridge 201

(R. L. WALKER presiding)

Contributed Papers on High-Energy Nuclear Physics

F1. Search for a Neutral Meson of Zero I Spin.* NORMAN BOOTH, OWEN CHAMBERLAIN, AND ERNEST ROGERS, *Lawrence Radiation Laboratory, Berkeley.*—A search has been made for a neutral meson of zero I spin by means of the reaction $d+d \rightarrow He^4+\pi_0^0$. No evidence was found for the existence of the π_0^0 in the mass range zero to 1.7 times the $\pi^\pm$ mass. The upper limit of the cross section was 7×10^{-32} cm^2 for $\pi_0^0 \sim \pi^\pm$ mass. The reaction was studied by using 460-Mev deuterons from the Berkeley 184-inch cyclotron and a liquid deuterium target. Alpha particles produced at 0° in the laboratory system were selected by momentum analysis and by a counter telescope which measured time of flight, dE/dx, and differential range. The experiment also sets a limit on the validity of charge independence.

* This research was supported by the Air Force Office of Scientific Research, the U. S. Atomic Energy Commission, and the Office of Naval Research.

F2. Decay of Bound Mu Mesons. JON MATHEWS, *California Institute of Technology.*—The decay of negative mu mesons

from K-shell orbits is considered, especially in light of the recent experimental results of Lundy *et al.*[1] Nonrelativistic wave functions form the basis for most of the calculations, but relativistic and finite-nuclear-size effects have been estimated. The enhanced decay rate for $Z \approx 26$ reported in reference 1 is not predicted; the decay rate falls off monotonically with increasing Z. In addition to the total rate, decay electron spectra and angular distributions have been calculated, and will be presented.

[1] Lundy, Sens, Swanson, Telegdi, and Yovanovitch, Phys. Rev. Letters 1, 102 (1958).

F3. Neutron Emission Following μ^- Capture in Calcium.* ROBERT V. PYLE, JUSTO DIAZ, SELIG KAPLAN, AND BURNS MACDONALD, *Lawrence Radiation Laboratory, Berkeley.*—The number of neutrons emitted from calcium following μ^- capture has been measured at the 184-in. cyclotron with a neutron detector having an efficiency of $54.3 \pm 2.0\%$ for a fission-neutron energy spectrum. (For a slightly different geometry, the calculated relative detection efficiencies for 1-, 3-, 5-, and 7-Mev neutrons are 99, 95, 89, and 84%, respectively.) Preliminary analysis of the data yields $\bar{N} = 0.73 \pm 0.06$ for the average number of neutrons per nuclear capture, based on the fission-spectrum detection efficiency. The relationship between the experimental results and the neutron-energy-spectrum calculations of Dolinsky and Blokhintsev[1] for this closed-proton-shell nucleus will be discussed.

* Under the auspices of the U. S. Atomic Energy Commission.
[1] E. I. Dolinsky and L. D. Blokhintsev, Nuclear Phys. **10**, 527 (1959).

F4. Pion Mass Measurements Using Neutron Time-of-Flight Techniques.* ROY P. HADDOCK, ALEXANDER ABASHIAN, KENNETH M. CROWE, AND JOHN B. CZIRR, *Lawrence Radiation Laboratory, Berkeley.*—Standard time-of-flight techniques have been used to measure the velocities of neutrons emitted in the capture at rest of π^- mesons in hydrogen [$\pi^- + p \rightarrow \gamma + n$, $\pi^- + p \rightarrow \pi^0 + n$]. Flight paths of 17.50 ft were used to measure the π^- mass and 12.44 and 17.50 feet to measure the π^-,π^0 mass difference. The values obtained are $272.4 \pm 1.1 m_e$ for the π^- mass and $8.991 \pm 0.020 m_e$ for the π^-,π^0 mass difference, where only the statistical error is quoted. Details of the experiment, including possible systematic errors, background, etc., will be discussed and comparisons made with the results of other groups. Extensions of the measurement for longer flight paths are anticipated.

* Work was performed under the auspices of the U. S. Atomic Energy Commission.

F5. π^--p Elastic Scattering at 370 and 427 Mev.* LESTER K. GOODWIN, ROBERT W. KENNEY, AND VICTOR PEREZ-MENDEZ, *Lawrence Radiation Laboratory, Berkeley.*—The differential cross section for the scattering of negative pions from protons was measured for pion energies of 370 ± 9 and 427 ± 10 Mev. The pion beam was obtained from the 184-in. cyclotron and was momentum-analyzed by a wedge magnet. The beam energy and contamination were determined from ranges in copper. The pions were scattered from a liquid hydrogen target and detected by a three-scintillator counter telescope which discriminated against recoil protons and inelastic pions on the basis of range in absorbers placed between the scintillators. The telescope was calibrated in the pion beam over the range of energies and absorber thicknesses used. The data at each energy were least-squares fitted to a power series in the cosine of the center-of-mass scattering angle. A χ^2 test indicated D waves are necessary, and best fits include some F-wave contribution at both energies. The total elastic cross sections obtained from integrating the best-fit differential curves are 10.8 ± 0.2 mb at 370 Mev and 12.9 ± 0.4 mb at 427 Mev. Lower-energy data currently being taken will be discussed.

* This work was done under the auspices of the U. S. Atomic Energy Commission.

F6. Further Study of π^0 Mesons from $\pi^- + p$ at Rest.* W. SELOVE, M. GETTNER, AND H. BRODY, *University of Pennsylvania.*†—The possible existence of a π_0^0 meson ($T=0$) with mass relatively close to that of the ordinary π^0 has not been excluded with very high certainty by past knowledge. The previously reported study[1] of the $\pi^- + p \rightarrow \pi^0 + n$ reaction has been pursued with much improved statistical accuracy. The data thus far indicate that there is no relatively closely-spaced second group of π^0's produced in this reaction with intensity more than 10 to 15% of the main group.

* Work supported by the U. S.
† The experimental work was carried out at the Carnegie Institute of Technology.
[1] Gettner, Holloway, Kraus, Larde, Leboy, Selove, and Siegel, Phys. Rev. Letters 2, 471 (1959).

F7. Angular Distribution of Protons from π^--P Scattering at 925 Mev. B. T. FELD, B. MAGLIĆ,* AND C. A. DIFFEY, *MIT.*—The shape of the π^--P differential scattering cross section in the backward hemisphere is sensitive to such features as resonances, "spin-flip" interactions, etc. Since backward pion angles correspond to forward angles of recoil protons, we studied the proton distribution in the angular region 12°–90° (cm). Pions of kinetic energy 925 Mev from the Brookhaven Cosmotron[1] were incident on liquid hydrogen; emulsions were placed inside a Styrofoam target assembly, $\frac{1}{4}$ in. from the hydrogen. The temperature at the center of emulsions was 45°K; separate tests showed that emulsions can be used at this temperature without appreciable loss of sensitivity. Five exposures were made, two of which were for the measurement of the distribution of background tracks. Data will be presented and compared with those of Erwin and Kopp,[2] as well as with predictions based on different assumptions regarding the nature of the nearby resonances.

* Now at Lawrence Radiation Laboratory, Berkeley, California.
[1] Thanks are due E. O. Salant for invaluable aid in the conception, preparation, and execution of the exposures to the pion beam.
[2] A. E. Erwin, Jr., and J. K. Kopp, Phys. Rev. **109**, 1364 (1958).

F8. Polarization of Protons from the Photodisintegration of the Deuteron. J. PARKS, B. MAGLIĆ,* AND B. T. FELD, *MIT.*—A determination of proton polarization from $\gamma + D \rightarrow N + P$ could yield important information on the mechanism of the photodisintegration reaction. We placed nuclear emulsion pellicules next to a liquid deuterium target, irradiated by a 300-Mev bremsstrahlung photon beam. In a 2-hr exposure an integrated flux of $\sim 10^{11}$ equivalent quanta was incident on the target. To check our discrimination against background, we first obtained the excitation curve from 150 to 300 Mev by measuring the grain count and direction angle of every track. Good agreement with previous data was obtained. Then we proceeded to follow protons emitted at $40° \pm 20°$ until they scattered on emulsion nuclei or until their energies dropped to 90 Mev. By using our result on the analyzing power of emulsions[1] and the method of "maximum likelihood," the most probable magnitude of the polarization was determined for an average photon energy of 240 Mev.

* Now at Lawrence Radiation Laboratory, Berkeley, California.
[1] B. T. Feld and B. C. Maglić, Phys. Rev. Letters 1, 375 (1958).

F9. $\Sigma^- n$ Hyperfragment Production in Deuterium.* ORIN DAHL, NAHMIN HORWITZ, DONALD MILLER, AND JOSEPH MURRAY, *Lawrence Radiation Laboratory, Berkeley.*—We previously have reported an upper limit of 2% for the ratio of hyperfragment production when stopped K^- mesons induce the reaction (a), $K^- + d \rightarrow \Sigma^- + n + \pi^+$.[1] In a recent exposure of the LRL deuterium bubble chamber, 10 000

additional interactions of slow K^- mesons were produced. This permitted a redetermination of the hyperfragment branching ratio by a technique potentially more sensitive than that used before. We have examined only those reactions of type (a) in which the Σ^- comes to rest and is captured. Since the moderation time of the $\Sigma^- n$ fragment is 1.50×10^{-10} sec, while that of a typical free Σ^- is $\sim3.25\times10^{-10}$ sec, the fraction of hyperfragments among the capture events is substantially increased. Of the 212 captures resulting from 3000 events of type (a), 145 have been analyzed. All except two were readily eliminated for the hyperfragment interpretation.

Assumed Σ^- lifetime ($\times10^{-10}$)	Expected No. for 2% branching ratio	Probability for finding two or less $\Sigma^- n$ (%)
1.50	10	0.27
1.67	8	1.3
1.84	6	6.0

* Work under the auspices of the U. S. Atomic Energy Commission.
[1] Luis W. Alvarez, 1959 Annual International Conference on High-Energy Physics at Kiev (to be published).

F10. Lifetime and Decay Modes of Negative K Mesons.* NORRIS A. NICKOLS, CONRAD J. MASON, FRANCES M. SMITH, JOHN DYER, AND WALTER H. BARKAS, *Lawrence Radiation Laboratory, Berkeley.*—We have measured the mean life and the decay branching ratios of negative K mesons, using a large emulsion stack as the detector. An enriched beam was analyzed by 180-deg magnetic bending. In a systematic study of 2582 K^- mesons 86 events in flight with no stable prong, blob, or Auger electron were observed. Of these, 48 had one lightly ionizing secondary and 38 had no visible secondary. No τ^- were observed. Space angles were measured and momenta of secondaries were determined from their ranges or from blob-density measurements. The residual range accurately determined the K^--meson momentum at the decay point, because the 180-deg bending provided high momentum resolution. A probability analysis was used to calculate the relative populations of the various decay modes and of nuclear interactions that simulate decays. Independent estimates of upper and lower limits to the number of decays present were made. The percent branching ratios for the various decay modes measured are as follows: $K_{\mu2}^-(56.5\pm7.3)$, $K_{\mu3}^-(9.5\pm4.3)$, $K_{\pi2}^-(26.3\pm6.6)$, $K_{\pi3}^-(2.8\pm2.4)$, $K_{e3}^-(4.9\pm3.2)$, $\tau^-(0.0+2.1)$. The K^--meson mean lifetime is $1.25(+0.22, -0.17)\times10^{-8}$ sec.

* Under the auspices of the U. S. Atomic Energy Commission.

F11. Confirmation of the Strangeness, -2, Assignment for the Cascade-Hyperon Ξ^-.* D. J. PROWSE, *University of California, Los Angeles* (introduced by J. R. Richardson).—In the course of scanning a stack of emulsions exposed to the 1.1 Bev/c K^--meson beam of the Berkeley bevatron, designed by M. Good and H. K. Ticho,[1] an event has been found in which an incident K^- meson produces a cascade hyperon and a K^+ meson in a reaction with a bound proton. Strangeness balance in the reaction demands that the cascade hyperon shall have strangeness -2. Measurements on the kinematics of the hyperon decay give a mass value of 1319 ± 5 Mev in good accord with the value reported by L. W. Alvarez at the Kiev Conference on High-Energy Physics.[2]

* Supported in part by the U. S. Atomic Energy Commission.
[1] Alvarez, Eberhard, Good, Graziano, Ticho, and Wojcicki, Phys. Rev. Letters **2**, 215 (1959).
[2] L. W. Alvarez, mimeographed proceedings of the 1959 Kiev Conference on High-Energy Physics.

F12. Sign of the Nuclear Optical Potential for K^- Mesons. M. MELKANOFF, D. J. PROWSE, AND D. H. STORK, *University of California, Los Angeles.*—Following our previous work[1] from which it was clear that to obtain the sign of the optical model potential from nuclear emulsion data, considerably better statistics than those available from 100 meters of track length between the energy range 30–90 Mev were required, we have analyzed new data at near 100 Mev. The energy spread of the scattered K^- mesons is small, about 20%, and from the known reaction cross section and the differential scattering cross section for emulsion nuclei obtained from 50 meters of track length followed, the sign of the potential appears attractive if reasonable values of the parameters in the Saxon well shape are assumed. The calculations were carried out on the IBM 709 at the Western Data Processing Center at UCLA. Our result is in agreement with the recent results on K^--P scattering presented by L. W. Alvarez at the Kiev Conference on High-Energy Physics.

* Supported in part by the U. S. Atomic Energy Commission and the National Science Foundation.
[1] Prowse, Melkanoff, and Stork, Bull. Am. Phys. Soc. Ser. II, **3**, No. 8, 401 (1958) and to appear in Nuovo cimento.
[2] L. W. Alvarez, mimeographed proceedings of the Kiev Conference on High Energy Physics (1959).

F13. Angular Distribution of the Reaction $K^+ + N \rightarrow K^0 + P$ at 260 Mev.* E. HELMY, D. J. PROWSE, AND D. H. STORK, *University of California, Los Angeles.*—The distributions in both energy and angle have been measured for the fast protons created by the reaction of about 260-Mev K^+ mesons with bound nucleons in emulsion nuclei. A comparison between those obtained for the charge-exchange reaction and the noncharge exchange reactions indicates that the angular distribution of the reaction $K^+ + N \rightarrow K^0 + P$ is peaked forward. This result is in disagreement with a recent analysis of the Padova group.[1] Although a forward peaking is in agreement with the Pais theory,[2] the distribution is not known with sufficient precision to determine λ, an adjustable parameter in the derivation of the theoretical angular distribution according to the Pais supposition of odd relative parity of the K^+ and K^0 mesons.

* Supported in part by the U. S. Atomic Energy Commission.
[1] Ceolin, Dallaporta, Guerriero, Laboragine, Salandin and Taffara, circulated preprint to appear in Nuovo cimento.
[2] A. Pais, Phys. Rev. **112**, 624 (1958).

F14. Atomic Model for Physical Nucleons. L. E. H. TRAINOR, *University of Alberta.*—Feld[1] has shown how a simple atomic model of the physical nucleons can be used to account for their static properties and to give a quantitative description of such processes as meson photoproduction. This raises the question, to what extent can an atomic model be used to replace the field theory description of the π-meson nucleon interaction. The following atomic model for the physical nucleons has been considered by Trainor and Sood[2] in connection with the properties of nuclear matter. The physical nucleon is represented by a spin $\frac{1}{2}$ core of pseudo charge g interacting through a pseudo-Maxwell field with a Klein-Gordon orbital particle (π meson) of pseudo-charge $-g$. On this model the internucleonic forces are short range screened Coulomb forces. The bound states of the π meson can be found easily in the massive core approximation. For a suitable strength of the pseudo-charge g, the ground state corresponds to a π meson circulating in a $P_{\frac{1}{2}}$ state of zero total energy. The implications of this result for the description of meson production in an atomic model will be discussed.

[1] B. T. Feld, Ann. Phys. **1**, 58 (1957); **4**, 189 (1958).
[2] L. E. H. Trainor and P. C. Sood, Nuclear Phys. **12**, (1959).

F15. Fixed-Angle Dispersion Relations for Scattering of Particles of Equal Mass. J. D. BJORKEN,* *Stanford University.*—By use of the Nambu representation, fixed-angle dispersion relations are derived in all orders of perturbation theory for the scattering of particles of equal mass. Singularities are confined to cuts along the real energy axis. If the lowest singularity for positive energy corresponds to a threshold of a physical process (in the physical region), partial-wave dispersion relations may be derived. This case is applicable to π-π and N-N scattering. In these cases, singularities along

the negative real energy axis due to production processes lie beyond those due to one- and two-meson exchange terms. In cases of "anomalous thresholds," the fixed-angle dispersion relations can be derived, at best, for a range of angles more limited than $(-\pi,\pi)$.

* Supported in part by the U. S. Air Force through the Air Force Office of Scientific Research.

F16. Spectrum of the Mu-Meson Primaries of Counter-Selected Mu-Electron Collisions in Carbon and Paraffin.* S. H. NEDDERMEYER, S. B. CURTIS, AND R. F. DEERY, *University of Washington.*—The momentum spectrum of the incident mu's selected by the experiment of the preceding abstract may be expected to be strongly dependent on the kind of material above the apparatus and the nature of the selected events. For the mu-e events alone the selected spectrum for this experiment should be expected at high momenta to approach the true spectrum of the total incident mu's, whereas, if pair and radiation events are also included, the lower primary momenta should be more strongly suppressed, and the measured spectrum should fall more slowly at high momenta. The primaries of those events that are apparently mu-e collisions have a differential spectrum, as determined by magnetic deflection, which falls about as $p^{-2.6\pm0.2}$ from 10 to 100 Bev/c. Unless processes are occurring which are not yet understood, it is presumed that the actual spectrum of the total incident mu's falls off faster than this.

* Supported by the Office of Naval Research.

MONDAY AFTERNOON AT 2:00

Kerckhoff 119

(C. D. ANDERSON presiding)

Contributed Papers on Plasma Physics and Cosmic Rays

G1. Microwave Absorption and Reflection Spectrum of a Plasma. W. D. HERSHBERGER, *University of California, Los Angeles.*—A series of absorption and reflection peaks at microwave frequencies has been reported by Rommel and by Dattner for plasmas cylindrical in form. One peak occurs at the electron density appropriate to the conventional plasma frequency, while the others occur at electron densities lower than that for the principal resonance. This paper describes experiments conducted at a fixed frequency of 2985 mc and the resonances are observed both when the plasma column is enclosed in a wave guide and when it is used in free space reflection experiments. The incident electric field is perpendicular to the axis of the plasma column. The positions of the peaks are given by the dispersion-interference relationship

$$2n/(2n+1)=[1-(f_0/f)^2]^{\frac{1}{2}},$$

and the mode spectrum is found by assigning integral values, including zero, to n. By using the Bohm-Gross dispersion equation, the foregoing relationship identifies a set of ratios between phase velocity of the plasma wave and rms electron velocities such that simultaneously the conditions are met for the existence of a standing plasma wave and a stationary pattern of electron motion. Applications to radar echoes from meteor trails is indicated.

G2. Instability of Contra-Streaming Plasmas. PAUL J. KELLOGG AND HAROLD LIEMOHN,* *University of Minnesota.*—The problem of instabilities in colliding ionized hydrogen beams which has been treated by Kahn[1] and Parker[2] in the special case of zero temperature, is solved for the nonzero temperature case by taking Maxwell distributions for the equilibrium density functions. At sufficiently high temperature it is found that the random thermal motion will prevent growing oscillations. The boundary between the stable and unstable regions is given as a function of energy and density parameters. Certain phenomena associated with solar particle streams are discussed in terms of these results.

* Now at Boeing Scientific Research Laboratories.
[1] F. D. Kahn, Revs. Modern Phys. **30**, 1069 (1958).
[2] E. N. Parker, Phys. Rev. **112**, 1429 (1958).

G3. Some Parameters of the Plasma Diode.* RAYMOND FOX, *Lawrence Radiation Laboratory, Livermore.*—A relationship has been derived which predicts the power radiated from the cathode to the anode of the plasma diode. The radiated power loss for a tungsten cathode and a nickel anode, predicted by this relationship, was found to be five times greater than the prediction of the relationship which assumes graybody conditions. The effective work functions of the cathode and anode of the plasma diode were found to be a function of the electrode separation and the grain sizes of the cathode and anode material. An upper limit of the thermoelectric power output of the cesium plasma was evaluated and found to be small compared with the total electrical power output of the diode. The use of barium vapor for the depression of the cathode work function and cesium vapor for space charge neutralization appears very promising for obtaining a high heat converter efficiency. A method also appears very promising in which the cathode is raised to such a high temperature that appreciable evaporation results.

* This work was performed under the auspices of the U. S. Atomic Energy Commission.

G4. Theoretical Calculations of Exploding Wire Phenomena.* CARL A. ROUSE, *Lawrence Radiation Laboratory, Livermore.*—Earlier calculations of exploding wire phenomena[1] have been extended. Instead of the instantaneous energy deposition in the wire and the assumption of a constant gamma-law-gas equation of state, the results of machine calculations will be presented in which the energy is assumed deposited uniformly in the material as $\sin^2(\pi t/T)$ and a variable gamma-law equation of state for the wire material is used. The equation of state used was derived from a simple solution of the equations describing ionization equilibrium[2] (this solution is to be published). The exploding wire event analyzed in this report was obtained at this laboratory by Woodruff. The present theoretical calculations of the shock front in air and the second shock in the copper gas show good agreement with the experimental results. Other interesting aspects of the event will be discussed.

* Work done under the auspices of the U. S. Atomic Energy Commission.
[1] C. A. Rouse, Lawrence Radiation Laboratory Rept UCRL-5519-T (March 1959).
[2] L. D. Landau and E. M. Lifshitz, *Statistical Physics* (Addison-Wesley Publishing Company, Reading, Massachusetts, 1958), p. 322.

G5. Exploding Wire Facility.* WAYNE R. WOODRUFF, *Lawrence Radiation Laboratory, Livermore* (introduced by

Carl Rouse).—Two switching systems have been used for the generation of cylindrical shock waves by discharging a capacitor bank into a wire. One system utilizes spark gaps[1] for switching and another uses a low-pressure, low-inductance switch[2] to discharge up to 1350 joules into the wire in 0.3 μsec. In both systems, the wire can be exploded under pressure or in vacuum. The voltage across the wire and rate of change of current through the wire are recorded. The radial growth of the air shock and the wire are observed with a rotating-mirror camera operating up to 4000 rps.[3] The spectra emitted (and absorbed) during the explosion are also observed with the camera. The data are analyzed with the aid of computer codes.[4]

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] H. B. McFarlane, Lawrence Radiation Laboratory Rept. No. UCRL-5290 (August, 1958).
[2] W. R. Baker, Rev. Sci. Instr. **30**, 700 (1959).
[3] A. C. Graves and D. K. Froman, *Miscellaneous Physical and Chemical Techniques of the Los Alamos Project* (McGraw-Hill Book Company, Inc., New York, 1952), first edition.
[4] C. A. Rouse, Lawrence Radiation Laboratory Rept. No. UCRL-5519-T, (March, 1959); Bull. Am. Phys. Soc. Ser. II, **4**, 449 (1959), preceding paper.

G6. Arc Spot Propagation on the Ignitron Cathode.* DAVID B. CUMMINGS, *Lawrence Radiation Laboratory, Livermore* (introduced by David Sloan).—Kerr-cell photographs have been taken on a glass ignitron carrying up to 25 000 amp with a rise time as short as 1.25 μsec. These show a disk of light bounded by arc spots spreading out on the mercury from the ignitor with velocities up to 2×10^6 cm/sec. The peak velocity is proportional to the 0.7 power of the peak tube current and directly proportional to the non-inductive component of tube voltage drop. The tube volume shows early growing striations and occasional pinches. Later exposures show cathode vapor jets and anode spots.

* Work was performed under auspices of the U. S. Atomic Energy Commission.

G7. Intensity Distribution of Vacuum Ultraviolet Radiation Emitted from Magnetically Driven Shock Plasmas.* J. A. R. SAMSON, D. ROBINSON, AND G. L. WEISSLER, *University of Southern California*.—A one-half m normal incidence vacuum spectrograph with a reciprocal dispersion of 17 A/mm has been used to observe the vacuum ultraviolet spectra in argon and other gases emitted from magnetically driven shock plasmas. Both the conical tube[1] and the T-tube with back strap[2] were used as drivers to produce shock plasmas in the cm/μsec range. Curves showing the relative intensity of the vacuum ultraviolet radiation, corrected for the reflectivity of the aluminized grating, will be presented.

* The support of Office of Ordnance Research and the Office of Naval Research is gratefully acknowledged.
[1] V. Josephson, J. Appl. Phys. **29**, 30 (1958).
[2] A. C. Kolb, Phys. Rev. **107**, 345 (1957).

G8. A Multistage Hypervelocity Projector.* M. H. BENGSON AND T. K. SLAWECKI, *General Electric Company, Aerosciences Laboratory* (introduced by P. Gloerson).—There exists at present a need for hypervelocity projectors capable of accelerating projectiles to velocities far in excess of those obtainable using conventional light guns and high explosives driven systems. The study described explored the feasibility of using an acceleration technique in which a projectile is subjected to repeated high-pressure pulses resulting from stagewise addition of lithium hydride and electrical energy behind the moving projectile. Gas dynamics calculations for each stage performed using the method of characteristics have shown that in order to accelerate a 3-g projectile from 10 000 to 50 000 ft/sec, a 9-stage projector is required. The total length of projector was calculated to be 610 cm; the minimum electrical energy 685 kj, and the total amount of propellant (LiH) 4g. The experimental program directed toward the study of action of high-voltage arcs on lithium hydride and of the timing of mass and energy addition showed the practicability of such a device.

* Supported by the U. S. Air Force.

G9. Latitude Dependence of Primary Cosmic Radiation in 1958. HUGH R. ANDERSON, *California Institute of Technology* (introduced by H. V. Neher).—During the summer and fall of 1958 the ionization produced in the atmosphere by cosmic radiation was measured at 31 latitudes ranging from 80°S geomagnetic to 83°N. The measurements were made with balloon-borne integrating ionization chambers at air pressures from approximately 500 g/cm² to 15 g/cm² at each latitude. A similar measurement at one of two base stations was made simultaneously with each of these. The data obtained at the base stations show variations in the rate of ionization as great as 10% at pressures less than 50 g/cm². These variations do not appear to be entirely random in time. The dependence of the rate of ionization upon geomagnetic latitude shows a sharp knee in both northern and southern hemispheres between 50° and 60° geomagnetic latitudes. Even when one uses the eccentric dipole coordinates to define latitude the data show an asymmetry about the magnetic equator. If time permits, similar data obtained in other years will be shown to point out the profound changes which have occurred in the rate of ionization from one year to another.

G10. Cosmic-Ray Behavior during Onset of Geomagnetic Storms.* ROBERT L. CHASSON AND KAICHI MAEDA,† *University of Nebraska*.—Chree analysis of low-energy nucleonic cosmic-ray data, recorded over forty 15-min intervals, showed specific recurrent behavior during times of onset of geomagnetic storms. Thirty-three events (chosen from IGY) accompanied by Forbush decreases in the daily average intensity were included in the superposition.[1] There was a definite quieting of fluctuations for a 2- to 2½-hr period, centered upon storm commencement time, followed by a recurrent intensity surging with a period of approx. 1½ hr and peak-to-peak relative amplitude of 1½%. Such behavior was not observed for 41 storms not accompanied by Forbush decreases. Further Chree analysis shows no resemblance between detailed cosmic-ray changes and horizontal magnetic intensity fluctuations in the corresponding Koror magnetograms. Apparently cosmic-ray nonstatistical fluctuations do not correspond in short-time detail with changing electromagnetic conditions near the earth. Further analysis includes later times on the Forbush decrease fronts to determine persistence and damping characteristics of the observed periodicity.

* Supported by IGY Grant No. Y/2.15/135 of the National Science Foundation.
† Now at the University of Maryland.
[1] Robert L. Chasson and Kaichi Maeda, Proceedings of the International Conference on Cosmic Rays (IUPAP), Moscow, July 6–11, 1959 (unpublished).

G11. Argon Diffusion Losses of Meteorites in Flight. GORDON G. GOLES, ROBERT A. FISH, AND EDWARD ANDERS, *University of Chicago*.—Although the K-Ar ages of meteorites are systematically lower than the Rb-Sr and Pb-Pb ages, the argon retention in chondrites and most achondrites has been high. Assuming the losses in chondrites to have been restricted to the cosmic-ray exposure era ($\sim10^7$ yr) a maximum value of 1.5×10^{-17} can be established for the parameter D/a^2, D being the diffusion coefficient and a the radius of the grains in which K is embedded. The results of Geiss and Hess on argon expulsion in chondrites are extrapolated to show that D/a^2 is so low only at temperatures below 225°K. Evidence is presented to show that this temperature applies to other classes of stone meteorites. From an equation relating the radiation temperature of a spherical object to its distance from the sun it becomes apparent that the meteorites must have travelled on eccentric orbits passing through the

asteroidal belt, with perihelia near 1 au. This conclusion is confirmed by considering diffusive losses occurring within parent bodies in orbits nearer the sun than the asteroidal belt. The size of these parent bodies was <250 km, because long-lived radioactivities would preclude the observed degree of argon retention in larger objects.

G12. Propagation of Intense Shock Waves into the Earth. HYMAN SERBIN, *Hughes Aircraft Company.*—The propagation of pressure into the earth following a blast at the surface is studied. The earth is regarded as a compactible medium composed of solids, water, and air; it is assumed that the air spaces close up following an impulsive loading. With this model, the theory leads to a formula for the attenuation of maximum stress with depth which is confirmed by data from nuclear bomb tests. Partial confirmation is also obtained between the theoretical and test values of particle velocities and displacements.

TUESDAY MORNING AT 9:30

Culbertson Hall

(R. F. CHRISTY presiding)

Invited Papers on High-Energy Nuclear Physics

H1. Survey of the Pion-Nucleon Interaction at Energies above the First Resonance. V. PEREZ-MENDEZ, *University of California, Berkeley.* (20 min.)

H2. Review of Present Status of the K^--Nucleon Interaction. F. T. SOLMITZ, *University of California, Berkeley.* (30 min.)

H3. Possible Manifestations of a Pion-Pion Interaction. G. F. CHEW, *University of California, Berkeley.* (30 min.)

H4. Experimental and Theoretical Studies of Extensive Air Showers. S. OLBERT, *Massachusetts Institute of Technology.* (40 min.)

H5. Nuclear Interactions at Extreme Relativistic Energies. M. SCHEIN, *University of Chicago.* (30 min.)

TUESDAY MORNING AT 9:00

Bridge 201

(H. MCCONNELL presiding)

Resonance and Solid-State Physics I

Invited Paper

I1. Measurements of the *g* Factor and Tests for an Electric Moment of the Free Electron. H. R. CRANE, *The University of Michigan.* (30 min.)

Contributed Papers

I2. Nuclear Magnetization Distribution of Two Mercury Isotopes from Their Knight Shifts. J. EISINGER, W. E. BLUMBERG, AND R. G. SHULMAN, *Bell Telephone Laboratories.*—A finite magnetic moment distribution inside the nucleus reduces the hyperfine interaction from what it would be for a point dipole moment.[1] The fractional reduction ϵ depends on the structure of the nucleus and has been calculated for $s_{\frac{1}{2}}$ electrons. For a pair of isotopes, 1 and 2, in a metal the $s_{\frac{1}{2}}$ conduction electron which is responsible for the Knight shift k causes different Knight shifts if the magnetization distribution for the two isotopes is not the same. If g^m and g are the effective g values in the metal and the free atoms, $\epsilon_1-\epsilon_2=(1/k)[(g_1^m/g_2^m)(g_2/g_1)-1]$. We have observed the nuclear magnetic resonance of Hg^{199} and Hg^{201} in a sample of finely dispersed metallic mercury at room temperature, and found $g_{201}^m/g_{199}^m=0.36915\pm0.00001$. Combining this result with the value[2] for the nuclear magnetic moments measured in free Hg atoms $\mu_{201}/\mu_{199}=1.10741\pm0.00001$ one finds $\Delta(s_{\frac{1}{2}})=\epsilon_{199}-\epsilon_{201}=-(0.16\pm0.10)\%$. In the metastable 6^3P_2 state of mercury, an atomic beam measurement[3] gives $\Delta(^3P_2)=-0.15\%$. These results will be discussed in the light of the theory of magnetization distribution and nuclear models.

[1] J. Eisinger and V. Jaccarino, Revs. Modern Phys. **30**, 528 (1958).
[2] B. Cagnac and J. Brossel, Compt. rend. **249**, 77 (1959).
[3] Faust, McDermott, and Lichten, Bull. Am. Phys. Soc. Ser. II, **3**, 371 (1958).

I3. Nuclear Spin of 16-hr Am^{242}.* J. WINOCUR, R. MARRUS, AND W. A. NIERENBERG, *Lawrence Radiation Laboratory, Berkeley.*—The spin of 16-hr Am^{242} has been measured by the atomic-beam magnetic resonance method. The result is $I=1$. The isotope is obtained from the $Am^{241}(n,\gamma)Am^{242}$ reaction on Am_2O_3. A beam of atoms is produced by reducing the oxide with lanthanum metal. The radioactive beam is collected on freshly flamed thin platinum disks which are counted in continuous-flow proportional counters. Three flop-in transitions were observed at several values of the magnetic field. Large quadratic shifts were observed in fields of only a few gauss, indicating a small hyperfine structure. This result is

important in the light of the difficulties in interpreting the Am^{242} decay scheme and level structure.

* This research was supported by the U. S. Air Force Office of Scientific Research, the U. S. Atomic Energy Commission, and the Office of Naval Research.

I4. Nuclear Spin of 9.9-min Cu^{62}.* BARBARA DODSWORTH, V. J. EHLERS, W. B. EWBANK, F. R. PETERSEN, AND H. A. SHUGART, *Lawrence Radiation Laboratory, Berkeley.*—The spin of 9.9-min Cu^{62} has been measured by the atomic beam method as $I=1$. The isotope was produced by decay of 9.3-hr Zn^{62}, which was formed by the reaction $Ni(\alpha,2n)Zn^{62}$ by using 40-Mev α particles. The Cu^{62} was extracted chemically every 60 min and electroplated from the solution. For normalization a small amount of 3.3-hr Cu^{61} was added to the chemistry. A comparison of the ratio of 9.9-min/3.3-hr material in the oven sample with the ratio of 9.9-min/3.3-hr material in the spin sample then indicated the presence or absence of a resonance. A resonance was indicated by an enrichment of Cu^{62} (spin 1) with respect to Cu^{61} (spin $\frac{3}{2}$) in the spin sample. In the spin search, each oven load was exposed on a single button at a radiofrequency corresponding to a particular value of spin. Spin values of 0, 1, 2, or 3 were tried at several values of the field. The sample corresponding to spin 1 consistently showed an enrichment of the Cu^{62}/Cu^{61} ratio over that of the oven sample.

* This research was supported by the Air Force Office of Scientific Research, the U. S. Atomic Energy Commission, and the Office of Naval Research.

I5. Hyperfine Structure of Ga^{67} and Ga^{68}.* V. J. EHLERS AND W. A. NIERENBERG, *Lawrence Radiation Laboratory, Berkeley.*—Hyperfine-structure separations of 78-hr Ga^{67} and 68-min Ga^{68} have been measured by means of an atomic-beam magnetic-resonance experiment using radioactive detection. The Ga^{67} has been measured in both the $^2P_{\frac{1}{2}}$ and $^2P_{\frac{3}{2}}$ electronic states, allowing a determination of the differential hyperfine-structure anomaly $^{67}\delta^{69}$, defined by

$$^{67}\delta^{69}=^{67}\Delta_{\frac{1}{2}}{}^{69}-{}^{67}\Delta_{\frac{1}{2}}{}^{69}=(\Delta\nu/a)^{67}(\Delta\epsilon/a)^{69}-1.$$

Ga^{68} has been measured in the $^2P_{\frac{1}{2}}$ state and has shown a very small magnetic moment causing an energy-level inversion. For an assumed positive magnetic moment, the decreasing energy-level sequence is $F=\frac{3}{2},\frac{1}{2},\frac{5}{2}$. The values obtained are

Ga^{67}	Ga^{68}
$^2P_{\frac{1}{2}}$ $a=$ 175.092±0.009 Mc	$^2P_{\frac{1}{2}}$ $\lvert a\rvert=$ 3.875±0.050 Mc
$^2P_{\frac{1}{2}}$ $b=$ 71.939±0.025 Mc	$^2P_{\frac{1}{2}}$ $\lvert b\rvert=$12.230±0.125 Mc
$^2P_{\frac{1}{2}}\Delta\nu=$2457.733±0.030 Mc	$^2P_{\frac{1}{2}}$ $b/a>0$
$\mu=$ +1.845±0.001 nm	$\lvert\mu\rvert=$ 0.0272±0.0008 nm
$Q=$ +0.217±0.009 barn	$\lvert Q\rvert=$ 0.037±0.001 barn

The nuclear moments are obtained from the Fermi-Segrè formula and the moments[1] of Ga^{71}. The magnetic moments contain no diamagnetic correction. By using the interaction constants[2] of Ga^{69} with our values for Ga^{67} yields $^{67}\delta^{69}=(6\pm5)\times10^{-3}\%$.

* This work was partially supported by the U. S. Atomic Energy Commission and the U. S. Air Force Office of Scientific Research.
[1] Way, King, McGinnis, and Lieshout, U. S. Atomic Energy Commission Rept. TID-5300.
[2] N. F. Ramsey, *Molecular Beams* (Oxford University Press, New York, 1956).

I6. Nuclear Spin of Yttrium-90.* F. R. PETERSEN AND H. A. SHUGART, *Lawrence Radiation Laboratory, Berkeley.*—The nuclear spin $I=2$ for radioactive yttrium-90 ($T_{\frac{1}{2}}=64$ hr) has been measured in the electronic states $^2D_{\frac{3}{2}}$ and $^2D_{\frac{5}{2}}$ by the atomic-beam magnetic-resonance method. The low-frequency "flop-in" resonances that were observed correspond to the transitions $F,m_F=9/2,-3/2\leftrightarrow9/2,-5/2$ and $F,m_F=7/2,-1/2\leftrightarrow7/2,-3/2$ in the $^2D_{\frac{3}{2}}$ state and to the transitions $F,m_F=7/2,-3/2\leftrightarrow7/2,-5/2$ in the $^2D_{\frac{5}{2}}$ state. All transitions were observed at fields of 8.5 and 17 gauss. Certain transitions observed at higher fields have given preliminary values for the interaction constants a and b. The radioactive isotope was produced from the stable metal by the reaction $Y^{89}(n,\gamma)Y^{90}$ in the Livermore pool-type reactor. Resonance detection was accomplished by collecting the radioactive atoms on sulfur-coated "buttons" which were later counted in continuous-flow beta counters. All spin buttons were decayed to verify the identity of the radioactivity.

* Supported in part by the U. S. Air Force Office of Scientific Research and the U. S. Atomic Energy Commission.

I7. Exciton States in Superconductivity. D. C. MATTIS, *IBM, Poughkeepsie.*—Because of the attractive interaction V responsible for superconductivity, it is possible to form coherent excited states of an excitonic nature, whose energy lies below that of the BCS energy gap $2\epsilon_0$. the condensation energy is a function of $N(0)V$, where $N(0)$ is the density of states at the Fermi surface. It is therefore suggested that electromagnetic absorption experiments locating the position of this energy level would lead to an independent check of the value of the parameter $N(0)V$ central to the BCS theory, and could also determine the dependence (or independence) of this parameter on isotopic mass. The excitonic energy Δ is approximately $\Delta=2\epsilon_0[1+\pi^2(N(0)V)^2]^{-\frac{1}{2}}$.

I8. Nuclear Quadrupole Resonance in Superconductors.* ROBERT H. HAMMOND AND W. D. KNIGHT, *University of California, Berkeley.*—Measurements have been made on gallium to $T/T_c=0.732(T_c=1.084°K)$. Attenuation of signal intensity results in $\lambda(0)=1200\pm100$ A. A frequency shift below T_c reaches a value of $+6\times10^{-3}\%$ at $T/T_c=0.732$. The nuclear spin-lattice relaxation rate increases appreciably just below T_c. This is consistent with previous results[1,2] concerning relaxation processes which depend on a magnetic hyperfine interaction with conduction electrons. However, a nuclear quadrupole interaction with conduction electrons may contribute to the relaxation.[3] On the basis of the BCS theory it can be shown that the quadrupole contribution to the rate, instead of showing an initial enhancement below T_c, drops exponentially to zero with an infinite slope at T_c. For gallium the magnetic hyperfine interaction seems to be predominant. The influence of the quadrupole mechanism may be appreciable, however, since the observed enhancement is smaller than it is for aluminum.[1,2] The quadrupole interaction may be larger in indium.

* Supported in part by the Office of Naval Research and the Alfred P. Sloan Foundation.
[1] L. C. Hebel and C. P. Slichter, Phys. Rev. 113, 1504 (1959).
[2] A. G. Redfield, Phys. Rev. Letters 3, 85 (1959).
[3] A. H. Mitchell, J. Chem. Phys. 26, 1714 (1957).

I9. Excitation of Spin Waves in Ferromagnets: Eddy Current and Boundary Condition Effects. P. PINCUS, *University of California, Berkeley.*—The boundary condition for the transverse magnetization is derived when there is a surface anisotropy field H_S. An estimate of the magnitude of the surface anisotropy is obtained for nickel and it is found to be strong enough to effectively pin the directions of the surface spins. It is also shown how an antiferromagnetic surface layer can pin the end spins. For $H_S\neq0$, spin wave modes can be excited by a uniform rf field in a ferromagnet. The power absorbed in each mode in an insulator is calculated as a function of the surface anisotropy field. For complete pinning, the power absorption per mode is found to fall off as k^{-2}, where $\mathbf{k}$ is the spin-wave wave vector. The excitation of exchange modes is calculated for a metal with eddy current damping. The eddy currents are found to have a large effect only on the long wavelength spin waves. The line shape and the shift in resonant frequency are calculated for a thick metal slab with H_0 normal to the slab. The eddy current line width and shift are found to be proportional to $\delta^{-1}A^{\frac{1}{2}}$ where δ is the skin depth and A is the Landau-Lifschitz exchange stiffness constant.

I10. Spin Wave Spectrum in Magnetic Films.* R. F. SOOHOO,† *MIT* (introduced by N. Menyuk).—The general spin wave spectrum in thin films, assuming spin-pinning at the film boundaries, is investigated. In Kittel's theory of spin waves in thin films only spin waves whose **k** vectors are directed in the direction of the applied field [normal to the film surface (z)] were considered in any detail.[1] The results of our calculation shows, however, that whereas the intensities of excitation of the resonant or nearly resonant spin waves whose **k** vectors are directed at large angles to the z direction at a given field and frequency are relatively small, their number per unit solid angle is very large. In the presence of film nonuniformity such as inhomogeneity in the uniaxial anisotropy in Permalloy films, spin waves other than the z-directed ones may be excited. The excitation of a large number of these nearly resonant spin waves gives rise to background absorption which obscures the sharp resonances of the z-directed spin waves. The possibility of coupling between spin waves and phonons is also briefly considered.

[1] C. Kittel, Phys. Rev. **110**, 1295 (1958).
* The work reported in this paper was performed by Lincoln Laboratory, a center for research operated by Massachusetts Institute of Technology with the joint support of the U. S. Army, Navy, and Air Force.
† Staff Member, Lincoln Laboratory, Massachusetts Institute of Technology.

I11. Dynamic Proton Polarization in Co^{++} and Cu^{++} Doped Hydrated Crystals. P. L. SCOTT, O. S. LEIFSON, AND C. D. JEFFRIES, *University of California, Berkeley.**—Proton resonance absorption at helium temperatures has been enhanced by the application of microwave power to forbidden electron transitions in paramagnetic ions in the same crystal.[1] The protons are those in the waters of hydration and in ammonium ions in $Zn(NH_4)_2(SO_4)_2 \cdot 6H_2O$, (ZAS), and $La_2Mg_3(NO_3)_{12} \cdot 24H_2O$, (LMN), doped with a small percentage of Cu^{++} or Co^{++}. The proton enhancement for Cu^{++} doped ZAS extends over a region several hundred gauss broader than that covered by the visible electron hfs lines. Subsidiary maxima and minima in the enhancement are observed which are uncorrelated with electron transitions. Enhancement for Cu^{++} doped LMN behaves in the fashion expected for dipolar coupling. Co^{++} doped ZAS behaves in a similar manner to Cu^{++} doped ZAS. Power dependences, relaxation times, and environmental effects are discussed as is the application of theories of paramagnetic relaxation to these processes.

* Supported in part by the U. S. Atomic Energy Commission and the Office of Naval Research.
[1] Leifson, Scott, and Jeffries, Bull. Am. Phys. Soc. Ser. II, **4**, 453 (1958), following abstract.

I12. Dynamic Proton Polarization in Ce^{+++} Doped Hydrated Lanthanum Magnesium Nitrate by Dipolar Coupling. O. S. LEIFSON, P. L. SCOTT, AND C. D. JEFFRIES, *University of California, Berkeley.**—We have enhanced[1] the proton polarization in hydrated crystals by the saturation of the forbidden electron resonances ($\Delta m_S = 1$, $\Delta m_I = \pm 1$) of paramagnetic ions contained in the same crystal. This effect has been investigated for Ce^{+++} doped $La_2Mg_3(NO_3)_{12} \cdot 24H_2O$, at 4.2 and 1.7 deg absolute. A microwave transmission system operated at 9.5 kmc/sec and a Pound-Knight oscillator operated at 17 to 18 mc/sec are used to observe simultaneously paramagnetic and proton resonance. The proton polarization is positive for $H_0 + g_n\beta_n H_0$, and negative for $H_0 - g_n\beta_n H_0$, as expected for dipolar coupling between the paramagnetic ions and the protons. The transient behavior of the enhancement has been studied as well as its power dependence. Maximum observed polarization (~20 times thermal) remains an order of magnitude below ideal theoretical prediction. The proton signal shape is indicative of protons with different local environments; the enhanced signal shape is dependant on microwave power.

* Supported in part by the U. S. Atomic Energy Commission and the Office of Naval Research.
[1] A. Abragam and W. G. Proctor, Compt. rend. **246**, 2253 (1958).

I13. Cyclotron Resonance in II-V Semiconductors. MIREK J. STEVENSON, *IBM.*—Search for cyclotron resonances was carried out at 24 000 Mc and below 2°K in a series of II-V semiconductor single crystals grown by Lyons and Silvestri of our laboratory. Two resonances were observed in n-type $CdAs_2$ single crystals pulled from melt of 99.999+% purity. The higher effective mass resonance was identified with electrons by impact ionization and by filtering the exciting light source. The data suggests an energy band model consisting of single energy ellipsoids for both electrons and holes with effective mass parameters $m_t = 0.57m_0$, $m_l = 0.16m_0$ for electrons and $m_t = 0.32m_0$, $m_l = 0.11m_0$ for holes. No resonances were found in bulk grown and pulled Cd_2As_2 crystals. A single orientation dependent resonance was observed in vapor grown Cd_2As_2 crystal for which Hall measurements showed the lowest carrier concentration of the three types of crystals and mobilities of 11 000 cm²/v-sec at room temperature. A single resonance line was also observed in CdSb crystal pulled from melt of 99.9999+% pure distilled cadmium and 99.999+% pure antimony. The observed absorption line showed no orientation dependence and no crystal size or shape dependence characteristic of plasma effects. The effective mass parameters for the foregoing compounds and their angular dependence will be reported.

TUESDAY MORNING AT 9:30

Arms 155

(G. L. WEISSLER, presiding)

Contributed Papers on Electron Physics and Spectroscopy

J1. Ratios of He^- to He^+ in He Beams in Gases at kv Energies.* T. JORGENSEN, JR., C. E. KUYATT, W. W. LANG, AND C. A. SAUTTER, *University of Nebraska.*—Measurements have been made of the current ratios of the negative helium ion beam to the positive helium ion beam coming from an ion exchange chamber containing hydrogen, helium, nitrogen, and oxygen gases at various pressures. These ratios do not reach saturation with gas pressure as is the case for a proton beam but reach a maximum and then decrease slowly with increasing gas pressure. A possible explanation is given in terms of metastable atoms in the beam. The maximum ratios for each gas reach a maximum and then decrease with increasing beam energy. The maxima occur at 95, 165, 60, and below 40 kev for these gases, respectively. The maxima are 7.1, 2.1, 5.5, and greater than 6.5, all times 10^{-4}, for these gases. The maximum fractions of helium negative ions to the total helium beam, including neutral atoms, emerging from the exchange chamber have been calculated and are 2.3, 0.95,

1.7, and 1.6, all times 10^{-4}. The maxima occur at 130, 200, 80, and 65 kev, respectively.

* Work supported in part by the U. S. Atomic Energy Commission.

J2. Fine Structure in the Variation of Secondary Yield with Angle of Incidence for Single Crystals.* R. W. Soshea and A. J. Dekker, *University of Minnesota.*—Results will be presented on the variation of the secondary emission with angle of incidence of the primary beam for single crystals of titanium. It has been found that superimposed on the normal increase with increasing angle of incidence there are a number of relative maxima. The most pronounced of these persist over a very wide range of incident energies and correspond to alignment of the primary beam with important zone axes. In addition, there are many smaller and narrower peaks. An interpretation of these observations will be given in terms of coherent elastic scattering of the incident electrons.

* This research supported by Wright Air Development Center.

J3. Field Emission Current from Silicon.* R. L. Perry and T. F. Morisky, *Linfield Research Institute.*—The current-voltage relationship has been measured for several silicon field emitters and is of the form expected from Stratton's[1] theory of field emission from semiconductors. The range of emitted currents covered in the measurements is from 1×10^{-4} to 3 μa for continuous emission and 1 to 440 μa for pulsed emission (80 and 30 μsec duration at 60 pps). A difference in the log I *versus* $1/V$ plot of the data from emitters made of n-type and p-type silicon has been observed and will be discussed. The field emission microscope patterns indicate that the emitter surfaces were nearly free of contamination.[2]

* This work was supported by the U. S. Navy through the Bureau of Ships.
[1] R. Stratton, Proc. Phys. Soc. (London) **B68**, 746 (1955).
[2] F. G. Allen (private communication).

J4. Mode Damping in Plasma Electron Sheath.* C. W. Hartman and D. H. Sloan, *University of California.*—For stability an electron sheath is formed by replacing the neutral body of plasma by the rigid surface of a secondary emitter in crossed fields. Repeated irregularities in the anode permit oscillations of coherent frequency, like a magnetron. These can be stopped if the cold cathode has slots cut in it to couple power through toward a damper placed on the back surface of the cathode. Cathode slots are not self-oscillatory as anode slots would be. This leaves the electron sheath available for investigations that could not be made with a real plasma and sheath. Three types of oscillations are found within the sheath.

* This work was supported by the Air Force Cambridge Research Center, Air Research and Development Command.

J5. Photoionization of Water Vapor with Mass Analysis of Ions.* J. A. R. Samson and G. R. Cook,† *University of Southern California* (introduced by G. L. Weissler).—Water vapor has been investigated using monochromatic photons with energy in the 10 to 25 ev (1250 to 500 A) range together with analysis of the ions formed by mass spectroscopy. The relative photoionization efficiency curve (ions per unit photon flux) for the H_2O^+ ion was found to have an appearance potential of 12.6±0.1 ev and six minima corresponding to higher excited states of the ion. These minima are in good agreement with electron impact experiments,[1,2] except for one at 20.3±0.4 ev not previously observed. The OH^+ curve has an appearance potential of 18.3±0.2 ev and a structure similar to that of the H_2O^+ curve beyond 18.3 ev.

* This work has been supported by the Cambridge Air Force Research Center.
† Present address: Space Technology Laboratory, Los Angeles 45, California.
[1] Mann, Hustrulid, and Tate, Phys. Rev. **58**, 340 (1940).
[2] W. C. Price and T. M. Sugden, Trans. Faraday Soc. **44**, 108 (1948).

J6. Monochromatic Photoionization of Ammonia with Mass Analysis of Ions.* G. R. Cook† and J. A. R. Samson, *University of Southern California* (introduced by G. L. Weissler).—Radiation from a Seya type vacuum uv monochromator has been used to ionize ammonia in the ionization chamber of a Nier type single focusing mass spectrometer.[1] Relative ionization efficiency curves (ions per unit photon flux) have been obtained for the primary ion NH_3^+, the dissociative ion NH_2^+, and the secondary ion NH_4^+ in the wavelength range 1250 to 500 A (10 to 25 ev). The appearance potential of NH_4^+ at 10.9±0.5 ev was found to coincide with that of NH_3^+, and its formation is attributed to an ion molecule reaction. The dissociative ionization process leading to the formation of NH_2^+ occurred at 15.8±0.1 ev and agrees with the electron impact value.[2] Eight minima were observed in the ionization curve of NH_3^+, and are believed to indicate higher excited states of the ion. Minima at 14.9±0.8 and 22.3±1.0 ev are in fair agreement with 15.2 and 22.4 ev obtained by Lindholm[3] in his ion impact experiments.

* Supported by the Air Force Cambridge Research Center.
† Present address: Space Technology Laboratories, Los Angeles 45, California.
[1] Weissler, Samson, Ogawa, and Cook, J. Opt. Soc. Am. **49**, 338 (1959).
[2] Mann, Hustrulid, and Tate, Phys. Rev. **58**, 340 (1940).
[3] E. Lindholm, Z. Naturforsch. **9a**, 535 (1954).

J7. Micromass Measurement with 10 to 50 A X-Radiation. Burton L. Henke, *Pomona College.*—Because of the relatively large values of the photoelectric absorption cross sections and unit decrements of refractive index for the ultrasoft x-rays, these radiations are very useful for micromass determinations. Sufficient absorption signal for precise analysis for film mass thicknesses of the order of 10^{-4} to 10^{-5} g/cm^2 can be obtained. By simple x-ray microscopy techniques, the total mass of micron-size systems can be measured to within about 10^{-12} g. And by means of grazing incidence reflection studies, the density of surface films may be determined characterizing the material in the layer thickness of the order of 100 A. Special methods and instrumentation have been developed in this laboratory for this type of microanalysis. In order to support the design and interpretation of such measurements, extensive tabulations for the dispersion and the reflection of ultrasoft x-radiations have been made based upon the deduction of transitional probabilities from measured photoelectric cross-section data.

J8. Hyperfine Structure, Zeeman Effects, and Classification of Lines in Terbium Spectra. Sumner P. Davis, *University of California, Berkeley.*—Hyperfine structure splittings have been measured for 232 lines in the terbium spectra, Zeeman effects for approximately 600 lines, and relative intensities in arc and spark spectra for approximately 3500 lines. The splittings form a practically continuous range of values within the limits of measurement errors making an atomic energy level analysis impractical although large deviations from the interval rule are observable. Nearly 90% of the Zeeman patterns are unresolved, but sufficient information is obtainable to indicate that the ground state electronic configuration of terbium is still in doubt. The relative intensity measurements may prove helpful in an atomic energy level analysis.

J9. Position Dependence of Collision Induced Satellites of Alkali Lines on the Nature of the Alkali.* Shang Yi Ch'en and Ralph A. Wilson, Jr., *University of Oregon* (introduced by R. T. Ellickson).—The dependence of the positions of both the red and the violet absorption satellites of alkali lines, resulted from collisions between the alkali atoms and various foreign gases, on the nature of alkalis was investigated from the microphotometer traces of over 100 satellites of the absorption lines of Li, Na, K, Rb, and Cs in the presence of He, Ne, Ar, Kr, and Xe. For a given foreign gas, the absolute magnitudes of satellite-line separation, $|\Delta\nu|$ in cm^{-1}, for both

red and violet satellites decreased with increasing atomic weight of the alkalis; while for a given alkali, the $|\Delta\nu|$ increased for red satellites but decreased for violet satellites with the atomic weights of the foreign (perturbing) gas. Red satellites were observable only for heavy gases (Kr and Xe). The red satellite separation had a peak value for the third member of Li and for the second member of other alkali absorption series. Violet satellite separations were very large for the resonance lines but decreased so rapidly for the higher members that for heavy gases (Kr and Xe) no bands were resolved for the second or higher members of the principal series.

* Sponsored by the Office of Ordnance Research, U. S. Army.

J10. Calculated Wave Numbers, Thermodynamic Properties, and Rotational Distortion Constants for Some Deuterated and Tritiated Molecules.* S. SUNDARAM, G. THYAGARAJAN, AND FORREST F. CLEVELAND, *Illinois Institute of Technology.*—The complete set of quadratic potential energy constants obtained from investigations in this laboratory on NH_3, PH_3, and AsH_3 and the corresponding deuterides has been used to calculate the harmonic wave numbers for the molecules NT_3, PT_3, AsT_3, and the molecules of the type XYZ_2 (X=N,P,As; Y,Z=H,D,T). By using these wave numbers, the thermodynamic properties of those molecules have been obtained for a rigid-rotor harmonic-oscillator approximation. For NT_3, PT_3, and AsT_3, the anharmonicity factors obtained by a method due to Dennison have been used to predict the spectral frequencies. A first-order perturbation calculation of the rotational distortion constants for the 3 molecules has been carried out. The calculation of the rotational distortion constants for the other molecules is in progress.

* Supported by a grant from the National Science Foundation.

J11. Nitric Oxide Constants from Microwave Spectroscopy. V. E. DERR AND J. J. GALLAGHER, *The Martin Company.*—The microwave spectra of nitric oxide has been studied for both the $^2\pi_{\frac{1}{2}}$ state and the $^2\pi_{\frac{3}{2}}$ state of the molecule. For the $^2\pi_{\frac{1}{2}}$ state, a set of constants was obtained[1] which gave a good fitting of the spectra for both $N^{14}O^{16}$ and $N^{15}O^{16}$; however, the large uncoupling effects in this state prevented calculations within the accuracy of the measurements. Recently, the first rotational transition in the $^2\pi_{\frac{1}{2}}$ state of $N^{14}O^{16}$ has been observed[2] and a satisfactory calculation has been made for this state. However, inconsistencies exist when one tries to calculate either spectrum from constants obtained from the other state. The present work gives a set of constants which accurately fits the lines found for both states for $N^{14}O^{16}$, and a value of the quadrupole moment of N^{14} is calculated from the combining of quadrupole hfs constants and magnetic hfs constants. A recalculation of the $N^{15}O^{16}$ spectrum is also presented.

[1] J. J. Gallagher and C. M. Johnson, Phys. Rev. **103**, 1727 (1956).
[2] Favero, Mirri, and Gordy, Phys. Rev. **114**, 1534 (1959).

J12. Anomalously High Diffusion of Boron and Phosphorus from Oxide Layers on Silicon at 700 to 900°C.* ADOLF GOETZBERGER AND WILLIAM SHOCKLEY, *Shockley Transistor Corporation.*—Predeposits made at 700–1000°C of boron and phosphorus on silicon from P_2O_5 and B_2O_3 sources in oxidizing atmospheres have been diffused at temperatures from 700 to 1300°C, and surface conductance and junction depth has been measured. One technique has involved removal of silicon by repeated cycles of steps (1) and (2): (1) is diffusion in steam with oxide growth; (2) is removal of oxide by HF. As much as 20 cy have been carried out on one specimen removing as much as 2 μ of silicon in 14 hr of diffusion. The results of these and other experiments are consistent with a model in which phosphorus and boron is very largely rejected by the growing oxide and diffuses at 700°C with up to 100 times the Fuller-Ditzenberger diffusion constants when within a few μ of the surface.

* Research supported by Air Force Cambridge Research Center.

J13. Uniform Avalanche Effects in "Multiple Predeposit" p-n Junction in Silicon.* BRUCE MCDONALD, ADOLF GOETZBERGER, AND CHARLES STEPHENS, *Shockley Transistor Corporation* (introduced by William Shockley).—Very uniform p-n junctions with junction depths of about 0.4 μ have been produced by predepositing phosphorus from a P_2O_5 source upon silicon, washing off the oxide with HF, repredepositing and rewashing several times; i.e., predepositing in several successive coats. These junctions give uniform avalanche light emission over mesas having areas of several square mm. The multiplication of a photocurrent in such a junction with a 25 v breakdown was observed up to multiplication values as high as 120. It followed the law $M(V)[1-V/V_B)^n]=1$ with $n=1.34$ for $0.6\leqslant V/V_B\leqslant 0.95$. It is concluded that the junctions studied are perhaps the most uniform reported to date as indicated by the exceptionally low value of n.

* Research supported by Air Force Cambridge Research Center.

J14. Transmitted Phonon Drag across a p-n Junction.* WILLIAM SHOCKLEY AND K. HUBNER, *Shockley Transistor Corporation.*—If an electric field E_p is applied in p-type material parallel to a p-n junction, a coherent transport of phonon drag will be transmitted across the junctions and will induce an electric field E_n in the n-type material. If the n layer has thickness L_n which is assumed large compared to the phonon-phonon mean free path $1_{\varphi\varphi}$, then the electric field in an "open-circuited" n layer is E_n and

$$E_p/E_n\cong[1+(n/n_{n\varphi})][1+(n_{p\varphi}/p)][1+(p/n_{pi})]\times(L_n/L_p^*)(k/Q_{\varphi n0}q)6\exp(W_s/1_{\varphi\varphi}),$$

where n is the electron density in the n layer, $n_{n\varphi}$ and $n_{p\varphi}$ are the densities at which phonon-carrier scattering equals phonon-phonon scattering, n_{pi} is the acceptor density which halves hole mobility, $Q_{\varphi n0}$ is the phonon-drag thermoelectric power[1] at low electron density and W_s is the thickness of the space-charge layer. An experimental program to measure phonon mean free paths will be described.

* Research supported by Advanced Research Projects Agency—Office of Naval Research.
[1] C. Herring, *Semiconductors and Phosphors* (Interscience Publishers, New York, 1958), references 184–235.

J15. Spectral Emissivity of p-type Germanium in the 3-14 μ Region. DONALD L. STIERWALT, *U. S. Naval Ordnance Laboratory and University of Syracuse* (introduced by Roy F. Potter).—The emissivity of p-type germanium has been measured as a function of wavelength from 3 to 14 μ for several temperatures from 40 to 140°C. The thermal radiation from the sample was compared with that from a blackbody by means of a modified Beckman IR-3 spectrophotometer. Several prominent spectral features were noted, as well as a strong dependence upon temperature at the longer wavelengths. Values of emissivity from 0.15 to 0.4 were found.

J16. Kinetics of Recovery of Quenched-In Resistivity in Gold.* M. MESHII, T. MORI, AND J. W. KAUFFMAN, *Northwestern University.*—First-order annealing kinetics for quenching from 700°C in gold have been claimed by previous workers.[1] A fixed random-sink model based on this has been widely used. We find it is now necessary to revise these conclusions. The recovery of quenched-in resistivity was studied for quenching temperatures from 400°C to 700°C and for a wide range of conditions, i.e., different methods of quenching and various types of specimens and annealing baths. The electrical measurements were made in liquid helium in order to obtain an accuracy of 0.05% of the quenched-in resistivity quenched

from 600°C. The following conclusions are obtained: (1) For no range of quenching or annealing temperatures is a first-order process observed. (2) For quenches from about 600°C to 700°C the mode of decay is $\rho=\rho_0\exp(-kt^n)$ where $n=0.85$ and $n=0.77$ for quenches from 700°C and 600°C, respectively. (3) The foregoing mode of decay changes for quenches below 500°C where an initial increase of resistivity is observed upon annealing.

* Supported by the Office of Naval Research.
[1] J. E. Bauerle and J. S. Koehler, Phys. Rev. **107**, 1493 (1957).

TUESDAY AFTERNOON AT 2:00

McKinley Junior High School Auditorium

(H. BROWN presiding)

Invited Papers on Detection of Nuclear Explosions

K1. Introduction and Capabilities of Atmospheric Techniques. H. BROWN, *Lawrence Radiation Laboratory, Livermore.* (30 min.)

K2. Capabilities of the Seismic Method. C. ROMNEY, *USAF.* (30 min.)

K3. Improved Seismic Techniques. F. PRESS, *California Institute of Technology.* (25 min.)

K4. Coupling of Underground Explosions. E. A. MARTINELLI, *Rand Corporation.* (25 min.)

K5. Methods of Detection of Nuclear Explosions in the Upper Atmosphere and in Space. R. LATTER, *Rand Corporation.* (30 min.)

TUESDAY EVENING AT 7:30

Huntington-Sheraton Hotel

(G. E. UHLENBECK presiding)

Banquet of the American Physical Society

After-dinner speech: **There's Plenty of Room at the Bottom.** R. P. FEYNMAN, *California Institute of Technology.*

WEDNESDAY MORNING AT 9:30

Culbertson Hall

(A. R. HIBBS presiding)

Invited Papers on Space Physics

L1. Exploration of the Earth's Plasma Belts. C. W. SNYDER, *Jet Propulsion Laboratory.* (30 min.)

L2. Trapped and Cosmic Radiation Measurements from Explorer VI. J. A. SIMPSON, *Enrico Fermi Institute for Nuclear Studies, University of Chicago.* (30 min.)

L3. Rocket Surveys of Distant Magnetic Fields. C. P. SONETT, *Space Technology Laboratories, Inc.* (30 min.)

L4. Abundance of Chemical Elements. I. H. C. UREY, *University of California.* (30 min.)

L5. Abundance of Chemical Elements. II. H. E. SUESS, *University of California, La Jolla.* (30 min.)

WEDNESDAY MORNING AT 9:30

Bridge 201

(T. LAURITSEN presiding)

Invited Papers on Low-Energy Nuclear Physics

M1. Comparison of the Cross Sections for Neutron, Proton, and Alpha-Particle Emission from Excited States of Light Nuclei. T. W. BONNER, *Rice Institute.* (30 min.)

M2. Differential Elastic Scattering of Neutrons and Resonance Structure of Nuclei. J. L. FOWLER, *Oak Ridge National Laboratory.* (30 min.)

M3. Level Structure in the Sodium Isotopes. L. J. LIDOFSKY, *Columbia University.* (30 min.)

M4. The Chalk River Tandem Accelerator Research Program. H. E. GOVE, *Chalk River Laboratories, Atomic Energy of Canada, Ltd.* (30 min.)

WEDNESDAY MORNING AT 9:00

Arms 155

(R. L. WHITE presiding)

Solid-State Particle Detectors and Solid-State Physics

Invited Paper

N1. Semiconductor Devices as Particle Detectors. J. W. MAYER, *Hughes Aircraft Company.* (30 min.)

Contributed Papers

N2. Energy Lost per Electron-Hole Pair Created in Ge, Si, and Te. V. A. J. VAN LINT, H. ROTH, AND E. G. WIKNER, *General Atomic.**—The energy ϵ required to produce an electron-hole pair has been determined for germanium, silicon and tellurium using 25 Mev electrons from the General Atomic linear accelerator as an ionizing source. The experimental results which were obtained, in units of ev lost per electron-hole pair created, are as follows: (1) germanium, $\epsilon=4.0$ ev$\pm$15%; (2) silicon, $\epsilon=4.8$ ev$\pm$15%; and (3) tellurium $\epsilon=3.5$ ev$\pm$20%. These results were derived from measurements of temperature and conductivity changes due to pulses of ionizing radiation. The sum of the electron and hole mobilities at room temperature were assumed to be 5600, 1800, and 2000 cm²/volt-sec for Ge, Si, and Te, respectively. The rate of energy loss of 25 Mev electrons in these materials has also been measured. The experimental procedures and method of analysis will be described.

* John Jay Hopkins Laboratory for Pure and Applied Science, General Atomic Division of General Dynamics Corporation, San Diego, California.

N3. Gold-Silicon Surface Barrier Counters.* EMERY NORDBERG, *California Institute of Technology* (introduced by W. A. Fowler).—Charged-particle counters have been constructed by evaporating thin layers of gold on etched wafers of 300-ohm-cm *N*-type silicon. The room-temperature characteristics of such counters of area up to 50 mm² have been investigated. With the gold layer negative (reverse bias) the surface barriers have resistance of order 500 megohm and capacitances of order 500 $\mu\mu f/cm^2$. With high reverse bias, the rise time of the integral current pulse is a few μsec and ϵ approaches 3.8 ev per ion pair. Output pulse height is a linear function of particle energy, allowing for energy loss in the gold layer, up to 6 Mev for alpha particles. A pulse height resolution of 1.2% for 5.3 Mev alpha particles has been observed on a 10 mm² counter. Noise, which increases with the age of the counter, limits use to particle energies greater than about ½ Mev.

* Supported in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

N4. Self-Consistent Calculation of Crystal Potential and Energy Bands of Silicon. LEONARD KLEINMAN* AND JAMES C. PHILLIPS,† *University of California, Berkeley.*—An approximately self-consistent crystal potential is constructed for Si from a superposition of free-atom core and a sampling of crystal valence band charge densities. Valence-core exchange is calculated directly from core wave functions while valence-valence exchange is included using momentum-independent and momentum-dependent approximations taken from the results for a free electron gas. The resulting crystal potential is surprisingly similar to one previously obtained by Woodruff[1] from a superposition of free-atom charge densities. The calculated valence wave functions in the core region differ substantially from those of Woodruff because of the variational method used by him to calculate wave functions in that region. As a result the calculated energy gap is changed from Woodruff's value of 4 ev to about 1.5 ev, in substantially better agreement with the experimental value (1.1 ev). The various uncertainties in the calculation are discussed; it is concluded that the relative position of levels near the band gap should be correct to within about 1 ev. Effective masses are also calculated and compared with experiment; the agreement is quite good.

* National Science Foundation Predoctoral Fellow.
† National Science Foundation Predoctoral Fellow, now at Royal Mond Laboratory, Cambridge, England.
[1] T. O. Woodruff, Phys. Rev. **103**, 1159 (1956).

N5. Surface Potential of Silicon. C. T. RAYMO, *Hughes Aircraft Company*, C. W. BRANDS, *Litton Industries, Inc.*, AND B. SCHWARTZ, *Hughes Semiconductors* (introduced by H. Winston).—A simple dc field-effect method of measuring the surface potential of semiconductors has been developed. The technique involves maintaining a rapidly applied high-strength dc field and observing the conductance changes. If the field is strong enough, the decay will trace out a curve which can easily be converted to yield the surface potential of the sample. The slowness of the measurement allows for a steady-state balance to be reached between the charges in the barrier region and those in the slow and fast surface states. The disadvantages of irreversible surface changes involved in using ambients and the hysteresis problem that exists in the ac technique are not encountered. The only limitation appears to be the necessity of achieving a field strong enough to sweep through the conductance minimum; this consideration is common to all field-effect techniques.

N6. High-Energy Electron Induced Changes in the Galvanomagnetic Properties of Tellurium at 78°K. E. G. WIKNER, H. ROTH, AND V. A. J. VAN LINT, *General Atomic.**—By using 25 Mev electrons from the General Atomic electron linear accelerator, single crystals of tellurium[1] have been irradiated at 78°K in order to study the changes in the galvanomagnetic properties. Measurements included the conductivity, Hall coefficient, and magnetoresistance up to a radiation dosage of 4×10^{14} electrons/cm² for samples with the current both parallel and perpendicular to the c axis. The mobility[2] $R_1\sigma_2$ as measured on the parallel sample increased from 6×10^2 to 7.5×10^2 cm²/v-sec at a flux of 1.5×10^{14} electrons/cm² and then decreased slightly. For the perpendicular sample, the mobility $R_3\sigma_1$ increased from 1.0×10^2 to 6.3×10^2 cm²/v-sec at the same flux and then remained constant. The conductivity increases linearly with irradiation in this region as does the reciprocal of the Hall coefficient. Annealing studies will also be reported.

* John Jay Hopkins Laboratory for Pure and Applied Science, General Atomic Division of General Dynamics Corporation, San Diego, California.
[1] Initial c-axis resistivity was 4 ohm-cm. Grown by the Czochralski technique by T. J. Davies and provided by G. D. Long, Honeywell Research Center.
[2] H. Roth, J. Phys. Chem. Solids **8**, 525 (1959).

N7. Anelastic Studies of MgO Single Crystals between Room Temperature and 1400°C.* R. CHANG AND H. HORI, *Atomics International.*—The low frequency internal friction of MgO single crystals was measured from room temperature to 1400°C. (a) Under about 700°C, the measurements are sensitive to previous heat treatment, revealing an age-hardening characteristic. (b) Between 700 and 1000°C, the data suggest the presence of relaxation process or processes due to interaction between impurities (possibly also imperfections) and moving dislocations. (c) Above about 1000°C, the internal friction increases exponentially with increasing temperature of measurement. The connection between these observations and the strength and flow properties of MgO single crystals will be discussed.

* Supported by the U. S. Atomic Energy Commission.

N8. Relative Magnitudes of the Diffusion Coefficients in α- and γ-Iron Determined from Sintering Data.* C. J. MEECHAN, *Atomics International.*—Sintering studies on thorium[1] have shown that the diffusion coefficient near the transition temperature for the fcc phase is approximately a factor of five greater than that in the bcc phase. In contrast, radioactive tracer studies[2] have shown that the diffusion coefficient in α-iron (bcc) is 300 to 600 times greater than that in γ-iron (fcc) near the transition temperature. Sintering studies have been conducted on α-iron and γ-iron near the transition temperature. Preliminary data indicate that the large change in the diffusion coefficient as observed by tracer studies is not present in the sintered specimens, which is consistent with the foregoing results for thorium. The different results observed for the tracer and sintering studies are interpreted as evidence for different predominant diffusion mechanisms in α-iron and γ-iron. Specifically, vacancy migration is the dominant diffusion mechanism for the fcc phase whereas a ring mechanism may be dominant for the bcc phase.

* Supported by the U. S. Atomic Energy Commission.
[1] C. J. Meechan, *Second Nuclear Engineering Scientific Conference* (Pergamon Press, New York, 1957), Vol. 2, p. 209.
[2] C. E. Birchenall and R. F. Mehl, Trans. Am. Inst. Mining Met. Engrs. **188**, 144, 1375 (1950).

N9. Vacancy-Solute Binding in Metals.* A. SOSIN AND L. RACHAL, *Atomics International.*—The existence of a binding energy E_b between vacancies and solute atoms in very dilute concentration in a solvent metal is expected to result in two distinct effects. (1) At high temperatures, an excess concentration of vacancies will be thermodynamically present in the alloy over that in the pure metal. This excess has an $\exp[-(E_f-E_b)/kT]$ temperature dependence, where E_f is the formation energy of vacancies in the pure metal. This excess may be observed by (a) direct measurements at high temperatures or (b) measurements at low temperatures following quenching. (2) Vacancies (a) created by plastic flow at reduced temperatures or (b) retained by quenching should be observed to migrate in two higher temperature ranges. The first of these migration stages is characterized by an energy of migration, E_m; the second should be characterized by the energy (E_m+E_b). Preliminary resistivity data obtained by techniques (1a) and (2a) indicate that in copper a measurable binding energy exists between vacancies and solute atoms whose atomic size is appreciably different from that of copper. Valence differences between solute and solvent atoms appear to be less important than size differences.

* Supported by the U. S. Atomic Energy Commission.

N10. Theory of Sintering Under Pressure. J. D. MCCLELLAND, *Atomics International.*—A theory of sintering under pressure has been developed. The model assumes that under an external pressure the material being pressed will behave as an ideal Bingham solid. Such plastic flow results in the closure of the isolated voids which constitute the porosity. The resultant equation gives the rate of densification in terms of the applied pressure, the viscosity, and the yield strength. An end point density is predicted and equations for its pressure and temperature dependence are derived. The model accurately describes the hot pressing characteristics of BeO.

N11. Rolling Friction on Single Crystals of Silver Chloride and Copper. LAWRENCE D. DYER, *General Motors Research Laboratories* (introduced by R. N. Hollyer).—Rolling friction on single crystals of silver chloride and copper was investigated as part of an attempt to relate friction to the crystal structures of the contacting surfaces. The general method was to roll a sapphire ball in various directions on a carefully prepared crystal of silver chloride or copper and to measure the force which opposed its motion. On the ⟨100⟩ face of copper, the rolling friction was found to increase 18% in changing from the ⟨100⟩ direction to the ⟨110⟩ direction while the track width *decreased* 10%. On silver chloride, the rolling friction decreased 28% in changing from the ⟨100⟩ direction to the ⟨110⟩ direction while the track width decreased 17%. Variations in the distribution of slip bands around the end of a track with crystal direction are reported. A tentative explanation is given of the variation in track width with crystal azimuth. This explanation is based on the anisotropy of the surface level ahead of the advancing ball. A tentative explanation is also given for the anisotropy found in sliding friction of pointed sliders. An explanation of the anisotropy of friction of a ball rolling or sliding on a crystal has not yet been found, but it is shown that the foregoing surface-level factor does not suffice.

N12. Mu Meson-Electron Collisions in Carbon and Paraffin.* R. F. DEERY, S. H. NEDDERMEYER, S. B. CURTIS, *University of Washington.*—Particles from cosmic rays are required to pass through 14 in. Pb above and 10 in. Pb below the apparatus. Knock-on electron events originating in a target above the top section of a three section 36 in. cloud chamber operating in a field of 11 000 gauss are detected with the aid of two proportional counters which sandwich the top section. Electrons and mu mesons are identified by their behavior in traversing Pb plates above and below the middle section. The target was 23.1 g/cm^2 of carbon in one experiment and 18.3 g/cm^2 of paraffin in the other. Energies of the electrons and muons are determined from track curvature measurements, and events accepted only when the electron energy is greater than 100 Mev and the mu energy is from 5 to 50 Bev. More than 300 events with four-momentum transfers from 15 to 90 Mev/c (electron energies 0.2–8 Bev) have been recorded. At least 50 have transfers in excess of 30 Mev. The distribution of electron energies is compared with theoretical predictions based on quantum electrodynamics (Q.E.D.) modified by a one parameter form factor. Preliminary results are in rough agreement with unmodified Q.E.D. Results of a more complete analysis will be given.

* Supported by the Office of Naval Research.

WEDNESDAY AFTERNOON AT 1:45

Culbertson Hall

(H. V. NEHER presiding)

Invited Papers on Solar Cosmic Rays

O1. High-Latitude Ionospheric Absorption of Radio Waves as a Detector of Solar Cosmic Ray Bombardment. H. LEINBACH, *University of Alaska.* (30 min.)

O2. High-Altitude Observations of Intense Solar Cosmic Rays. (a) Intensity and Time Variations Observed with Counters and Ionization Chambers. J. R. WINCKLER, *University of Minnesota.* (30 min.)

O3. High-Altitude Observations of Intense Solar Cosmic Rays. (b) Energy Spectra and Composition Observed with Nuclear Emulsions. E. P. NEY, *University of Minnesota.* (30 min.)

O4. Cosmic-Ray Protons and Alpha Particles from the Sun. P. MEYER, *University of Chicago.* (20 min.)

O5. A Consideration of the Possible States of the Interplanetary Medium. L. DAVIS, JR., *California Institute of Technology.* (25 min.)

WEDNESDAY AFTERNOON AT 1:45

Bridge 201

(F. BOEHM presiding)

Contributed Papers on Low-Energy Nuclear Physics II

P1. Determination of the Low Energy Region of the Tritium Beta Spectrum. D. C. CONWAY AND W. H. JOHNSTON, *Purdue University.*—The tritium beta spectrum of HT has been carefully examined in a proportional counter spectrometer fitted with field adjusting electrodes to correct for the end effect. Below 1.2 kev the experimental spectra exhibit positive deviation from the theoretical spectrum which was corrected for the screening effect and counter resolution. Of the various possible instrumental distortions considered which might account for the deviation (+6.5% at 0.3 kev), the only possible one is that w, the energy to produce an ion pair in the counting gas, increases by several percent in the energy interval 1.2 to 0.25 kev.

P2. Radionuclide Sc^{40}.* FELIX SCHWEIZER AND J. REGINALD RICHARDSON, *University of California, Los Angeles.*—Sc^{40} was obtained by bombarding natural calcium metal with 20-Mev protons in the U.C.L.A. cyclotron.[1] The target was transferred pneumatically into a 180° uniform field spectrometer equipped with a gamma-ray monitor. The pulses from the beta-ray detector and the gamma-ray detector were recorded simultaneously on two-channel magnetic tape in order to sum the decay curves over a large number of bombardment cycles. The half-life of the high-energy positron group agreed with the half-life of the gamma decay, which was found to be 0.179±0.002 sec. The end point was found to be 0.24±0.11 Mev.

* Supported in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

[1] N. W. Glass and J. R. Richardson, Phys. Rev. **98**, 1251 (1955).

P3. Radioactive Decay of Ni^{56}.* D. O. WELLS AND S. L. BLATT, *Stanford University.*—Gamma rays originating in the radioactive decay of doubly magic Ni^{56} to Co^{56} have been studied using NaI(Tl) scintillation spectrometers. Sources were prepared by bombarding natural iron of high purity with 30-Mev alpha particles from the "Berkeley 60" cyclotron. The Ni produced was then chemically separated from the other reaction products obtained, which included Co^{56}, Co^{57}, Co^{58}, Mn^{52}, and Mn^{54}. Gamma rays of the following energies were observed: 0.17, 0.28, 0.49, 0.77, 0.83, 1.34, and 1.60 Mev. No evidence was seen for gamma rays of 0.950 and 1.74 Mev as previously reported.[1,2] Coincidences among the gamma rays have been measured and a decay scheme has been constructed. The intensity balance of the gamma rays in the decay scheme indicates that the predominant decay from Ni^{56} is to a 1.77-Mev level in Co^{56}. The decay appears to be primarily by electron capture.

* Supported in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.

[1] Raymond K. Sheline and Raymond W. Stoughton, Phys. Rev. **87**, 1 (1952).

[2] Joseph R. Wilkinson (private communication).

P4. Circular Polarization of Gamma Rays Following the Beta Decay of Fe^{59}. N. L. SANDERS, *University of Southern California* (introduced by H. H. Forster).—The asymmetry coefficient A, defined by $W(\vartheta)=1\pm A(v/c)\cos\vartheta$ has been measured for the two dominant decay modes in Fe^{59} using the method of forward scattering[1] from a magnetized Armco cylinder. The decay of Fe^{59} to Ni^{59} takes place mainly through the 271 kev beta-1.29 Mev gamma and through the 461 kev beta-1.099 Mev gamma cascades. As a check on the performance of the instrument the asymmetry parameter was determined for Co^{60} to be $A=-0.36\pm0.06$. Measurements for the 461 kev β-1.099 Mev gamma cascade were taken with the discriminator in the beta channel set above the end point of the 271 kev beta group. The asymmetry coefficient A for this transition was found to be $A=-0.46\pm0.08$ as compared with a theoretical value $A=-0.500$ computed[2] on the assumption of a pure GT beta transition followed by a pure $M1$[3] gamma ray. An attempt to determine the asymmetry coefficient for the 271 kev beta-1.29 Mev gamma cascade met with the difficulty that in this case a complete separation of the two groups was not possible.

[1] F. Boehm and A. H. Wapstra, Phys. Rev. **109**, 456 (1958).

[2] Alder, Stech, and Winther, Phys. Rev. **107**, 728 (1951).

[3] F. R. Metzger, Phys. Rev. **88**, 1360 (1952).

P5. Upper Limit for Parity Mixtures in Nuclear States. F. BOEHM* AND U. HAUSER, *University of Heidelberg.*—The gamma radiation emitted from nuclear states which are polarized by beta decay can show a 90 deg asymmetry if parity conservation in nuclear states[1] does not hold strictly. A beta-gamma angular correlation experiment delivers linearly the quantity $\mathfrak{R}\mathfrak{F}$ where $\mathfrak{F}$ is the relative amplitude of the irregular wave function with respect to the regular one and $\mathfrak{R}$ is the matrix-element ratio of the gamma transitions. $\mathfrak{R}$ can be estimated on the basis of a nuclear model. The measurements are performed with the beta-gamma decays of $A^{41} \rightarrow K^{41}$, $Xe^{133} \rightarrow Cs^{133}$, and $Lu^{177} \rightarrow Hf^{177}$ and result in the following upper limits for $\mathfrak{F}$: 2.10^{-4} for A^{41}, 2.10^{-4} and 8.10^{-6}, respectively, for Xe^{133}, considering two different estimates of $\mathfrak{R}$, and 3.10^{-3} for Lu^{177}.

* Permanent address: California Institute of Technology, Pasadena, California.
[1] See, for example, N. Tanner, Phys. Rev. **107**, 1203 (1957); D. H. Wilkinson, Phys. Rev. **109**, 1603, 1610, 1614 (1958).

P6. Mass and Angular Dependence of Prompt Neutron Emission from Single Fission Fragments. S. L. WHETSTONE, JR., AND W. E. STEIN, *Los Alamos Scientific Laboratory.**—The average number of prompt neutrons emitted within 60° (laboratory) to the flight path of one of the fragments from Cf^{252} fission has been measured as a function of the fragment mass. Fragment masses were determined from double-velocity time-of-flight measurements; the neutrons detected in a 30-in. cadmium-loaded liquid scintillator. In view of the surprising "discontinuity" in the dependence of the average number of neutrons per fragment on mass $\bar{n}(A)$ it was thought advisable to test for the possible existence of a large anisotropy in the c.m. angular emission of the neutrons. Since neutrons emitted near 90° (laboratory) from fragments of nearly "symmetric" mass are most easily carried into the forward hemisphere by the higher velocities of lighter fragments, it was conceivable that the present measurement, which excludes these "most sensitive" neutrons, might find the "discontinuity" gone. The present data, however, when appropriately corrected for the new detection geometry, *assuming isotropic neutron emission in the fragment systems*, reproduce the dependence $\bar{n}(A)$ determined previously.[1]

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] S. L. Whetstone, Jr., Phys. Rev. **114**, 581 (1959).

P7. Optical Model Calculation of the Differential Cross Section and the Polarization of Elastically Scattered Deuterons by Carbon. S. WATANABE,* *University of Washington.*—In view of the fact that the Born impulse and WKB[1] approximations are not satisfactory to predict quantitatively the polarization data of $E<140$ Mev deuterons elastically scattered nuclei, the differential equation derived in the reference[1] was solved numerically. We examined only the case of 94 Mev deuterons scattered by carbon nuclei with fixed radius and surface thickness but allowing the real and imaginary part of the central potential and the spin-orbit strength to be varied. No Coulomb force is considered.

* Guggenheim Fellow.
[1] Shigueo Watanabe, Nuclear Phys. **8**, 484 (1958).

P8. Asymmetry in "Coulomb Scattering" of 150 Mev Polarized Protons in Emulsions. B. MAGLIĆ,* AND B. T. FELD, *MIT.*—Polarization of protons scattered at small angles is expected, as a result of interference between the (repulsive) Coulomb scattering and the nuclear spin-orbit interaction.[1] Since our first report on small angle polarization,[2] we have made several attempts to measure this effect more accurately. Nuclear G-5 emulsions were exposed to a 72% polarized proton beam from the Harvard cyclotron. We looked for a scattering asymmetry at small angles (1.5°–3.5°) by three different methods: (1) along-the-track; (2) a modified multiple scattering technique in which the cell length was made equal to the mean free path for single scattering; (3) measuring angular distributions at two distances from the emulsion edge and looking for asymmetries which develop in the "tail" of the Gaussian. The results of these measurements, all indicating a small negative polarization, will be presented.

* Now at the Lawrence Radiation Laboratory, Berkeley, California.
[1] R. Sternheimer, Phys. Rev. **112**, 1785 (1959); this computation assumed a Wood-Saxon potential with a complex spin-orbit term. We have used a Gaussian potential real spin-orbit term in a WKB approximation. Both computations yield a small negative polarization at small angles.
[2] B. Maglić and B. T. Feld, Padua-Venice Conference (September, 1957), p. XVI-1.

P9. General Properties of the Gamma Correlation Function in the Adiabatic Approximation.* J. S. BLAIR AND L. WILETS, *University of Washington.*—The "preferred" direction, making equal angle with the incident and scattered directions in the scattering plane, represents an especially convenient axis of quantization for inelastic scattering in the adiabatic approximation, $|\mathbf{k}_i| = |\mathbf{k}_f|$. Although identical with the recoil direction $\mathbf{k}_f - \mathbf{k}_i$ in the adiabatic approximation, the "preferred" direction differs significantly from it for scattering in forward directions when the excitation energy is non-negligible compared with the initial or final projectile energy. For scattering of spinless projectiles from a spin zero target with the interaction represented by a static but otherwise general potential, it is demonstrated that only even-m states of the excited target are populated. The resulting gamma distribution is symmetric about the "preferred" axis. Further simplifications obtain in special cases. Since for spinless particles we can show quite generally that the scattered amplitude into the mth substate satisfies $f(m) = (-)^m f(-m)$, it follows[1] that the gamma distribution in the scattering plane for 0-2-0 excitation de-excitation has the form $a(\theta) + b(\theta) \sin^2[\theta_\gamma - \theta_0(\theta)]$. In the adiabatic approximation, the gamma distribution is $\sin^2[\theta_\gamma - \frac{1}{2}\theta]$ which is to be compared with the prediction in plane wave Born approximation $\sin^2[\theta_\gamma - \theta$ (recoil)]. These and related results are compared to experiment.

* Supported in part by the U. S. Atomic Energy Commission.
[1] C. A. Levinson and M. K. Banerjee, Ann. Phys. **2**, 471 (1957).

P10. Lifetime Matrix in Collision Theory. FELIX T. SMITH, *Stanford Research Institute.*—The *collision lifetime* is defined as the limit, as $R \rightarrow \infty$, of the difference between the time the particles spend inside R and the time they would have spent there in the absence of interaction. In nonrelativistic quantum mechanics, this leads to the *lifetime matrix* $\mathbf{Q}$. By using wave functions, ψ_i, normalized to unit flux or out through a sphere at $R \rightarrow \infty$, the matrix elements are

$$Q_{ij} = \lim_{(R\rightarrow\infty)} \left\langle \int^{\vartheta \leq R} \psi_i^* \psi_j d\tau - R(v_i^{-1}\delta_{ij} + \Sigma_k S_{ik}^* v_k^{-1} S_{jk}) \right\rangle_{Av}, \quad (1)$$

where averaging eliminates oscillations at large R, v_i is the velocity in the ith channel, and $\mathbf{S}$ is the unitary scattering matrix. The identity is proved: $\mathbf{Q} = -i\hbar \mathbf{S}^* d\mathbf{S}'/dE$. A diagonal element Q_{ii} is the average lifetime of a collision beginning in the ith channel. $\mathbf{Q}$ is Hermitian; its proper values, q_{ii}, are the lifetimes of metastable states if they are $\gg \hbar/E$. The causality principle finds its natural expression in $\mathbf{Q}$, as an inequality following from (1). Causality conditions are deduced for general inelastic scattering.

P11. Proton-Proton Effective Range Theory with Vacuum Polarization.* LEON HELLER AND MARTIN L. GURSKY, *Los Alamos Scientific Laboratory.*—Recent precision proton-proton scattering experiments at Wisconsin[1] strengthen the conclusion reached by Foldy, Eriksen, and Rarita, and Durand[2] that the vacuum polarization (v.p.) potential is present in the interaction between two protons. Considering the v.p. potential as perturbation, Foldy and Eriksen derived a correction ΔK to the effective range theory function $K \equiv C^2 kR \cot\delta + h(\eta)$. A difficulty with their procedure is that approximate p-p

wave functions have to be known to calculate ΔK; the shape-dependent parameter, because of its sensitivity to changes in K, may be strongly influenced by the assumed nuclear potential. By treating the Coulomb plus v.p. potentials as a unit the "electric" potential, we have derived a new modification in K which can be calculated without any knowledge of the nuclear potential. This formula will be discussed in detail, and the connection with the previous work, including the relation between the various phase shifts which are used, will be established. Some new values for the effective range parameters will be presented.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] Knecht, Messelt, Berners, and Northcliffe, Phys. Rev. 114, 550 (1959).
[2] L. L. Foldy and E. Eriksen, Phys. Rev. 98, 775 (1955); Eriksen, Foldy, and Rarita, Phys. Rev. 103, 781 (1956); and L. Durand, III, Phys. Rev. 108, 1597 (1957).

P12. Semiempirical Atomic Mass Law. PHILIP A. SEEGER, *Los Alamos Scientific Laboratory.*—The following expression for nuclear binding energy, found by least-squares analysis,[1] yields the experimental masses of 467 odd A atoms ($A>16$) with a root-mean-square error of 0.85 Mev/c^2:

$$E_B(\text{Mev}) = 16.93A - (33.10 - 57.99A^{-1/3})(I^2+2|I|)A^{-1} - 24.19A^{2/3} - 0.8076\left(\frac{Z^2}{A^{1/3}} - 0.7636\frac{Z^{4/3}}{A^{1/3}} - 2.29\frac{Z^2}{A}\right) + f(N) + g(Z) - \chi,$$

where $f(N)$ and $g(Z)$ consist of partial Fourier sine series expansions within each shell of N and Z, respectively, and χ is a constant. These functions show shell and deformation effects which are reasonable on the basis of current nuclear models within the limitations imposed by the use of separate functions[2] of N and Z.

* Now at Kellogg Radiation Laboratory, California Institute of Technology, Pasadena, California.
[1] F. S. Mozer, Phys. Rev. (to be published).
[2] Burbidge, Burbidge, Fowler, and Hoyle, Revs. Modern Phys. 29 (1957).

P13. Neutron Capture Chains in Heavy Element Synthesis.* D. D. CLAYTON, T. E. HULL,† AND W. A. FOWLER, *California Institute of Technology.*—The calculation of neutron capture chain abundances in the s process in stars can be reduced to superpositions of the special problem of one seed nucleus exposed to a neutron flux. Mathematical improvements on the method reported last year with Fe^{56} as the seed nucleus have been made.[1] The Laplace transforms of the exact solutions of the set $(dN_A/d\tau) = -\sigma_A N_A + \sigma_{A-1}N_{A-1}$, have been approximately matched to Laplace transforms of the function $(\sigma\tau)^{m-1}e^{-\sigma\tau}/\Gamma(m)$, where m and σ are functions of A, calculable in a prescribed manner from known or estimated neutron capture cross sections. Abundance distributions and the average number of neutron captures per seed nucleus resulting from the approximating function were calculated on a Datatron 205. The need for nonuniform exposure conditions, requiring large amounts of seed nuclei with small exposures and much smaller amounts in large fluxes, is apparent, as is a possible explanation of small σN values in the lead region. The relative abundance of the lead isotopes from the s process alone has been calculated, thereby requiring assignment of deviations from these expected limits to other production processes.

* Supported in part by the joint program of the Office of Naval Research and the U. S. Atomic Energy Commission.
† Now at the University of British Columbia.
[1] Clayton and Fowler, Bull. Am. Phys. Soc. Ser. II, 3, 407 (1958).

P14. Energy Generation Processes in the Stars. A. G. W. CAMERON,* *California Institute of Technology.*—In a massive star which can become hot enough to form the "iron equilibrium abundance peak" at the center, there are seven major energy generation sources, two of which may operate simultaneously. These are: (1) conversion of hydrogen to helium by proton-proton chains and carbon-nitrogen-oxygen cycles; (2) helium burning, forming mainly C^{12} and O^{16} (but probably Ne^{20} in a less massive star); (3) carbon burning, forming mainly Ne^{20}, Na^{23}, and Mg^{24}, and also heavy elements by neutron capture on a slow time scale; (4) neon burning, forming O^{16} and Mg^{24}; (5) oxygen burning, forming Si^{28} and S^{32}; (6) S^{32} and Si^{30} photodisintegrations, forming Si^{28}; and (7) photodisintegration of Si^{28} and Mg^{24}, initiating a network of reactions leading to Fe^{56} and neighboring nuclei. The following temperatures are roughly characteristic of these processes: (1) 2×10^7 °K; (2) 1.5×10^8 °K; (3) 7×10^8 °K; (4) 1.1 or 1.3×10^9 °K; (5) 1.3×10^9 °K; (6) 2×10^9 °K; and (7) 2.5×10^9 °K. The energy yields of these reactions decrease rapidly with complexity. Process (7) initiates a high rate of energy loss by neutrino and antineutrino emission in photobeta reactions, which more than cancels the energy gain from the nuclear transformations.

* On leave from Atomic Energy of Canada Ltd., where this work was done.

P15. On the Am^{242} Isomeric Pair.* F. ASARO, I. PERLMAN, J. O. RASMUSSEN, AND S. G. THOMPSON, *Lawrence Radiation Laboratory, Berkeley.*—The isomers of Am^{242} (half-lives 16 hr and ~100 years) have presented some major inconsistencies when attempts have been made to reconcile their apparent decay modes with existing selection rules for beta and gamma transitions. From measured energies of beta spectra the long-lived isomer has previously been presumed to be the ground state. We have found by an isomer separation technique that the 16-hr isomer is present in equilibrium with the long-lived isomer and hence is the ground state. Recent atomic beam studies[1] have shown the 16-hr Am^{242} to have spin 1 and a ratio μ/Q_{spec} which is negative, in contrast to neighboring Am^{241} and Am^{243}. We are able to explain theoretically most of the data on these isomers by couplings of the $5/2-$ proton orbital of the Am^{241} ground state with the $5/2+$ neutron of the Pu^{241} ground state to give an upper $5-(K=5)$ and a lower $1-(K=0)$ state, with the isomeric transition being a $K-$ forbidden $E4$. A negative spectroscopic quadrupole moment for the $1-$ isomer is a consequence of a positive intrinsic quadrupole deformation and the negative projection factor for $K=0$ states.

* This research was performed under the auspices of the U. S. Atomic Energy Commission.
[1] Winocur, Marrus, and Nierenberg, Bull. Am. Phys. Soc. Ser. II, 4, 451 (1959), this issue.

WEDNESDAY AFTERNOON AT 1:45

Arms 155

(W. D. KNIGHT presiding)

Contributed Papers on Resonance and Solid-State Physics II

Q1. Temperature Dependence of the NMR in Ferromagnetic Cobalt. V. JACCARINO, *Bell Telephone Laboratories.*—The variation with temperature of the Co^{59} NMR frequency in cobalt metal powder ($T_c=1394$°K) has been measured in the 1–550°K temperature range in zero external magnetic field.[1] The normalized fractional decrease of the frequency

with temperature may be fitted using the relation $aT^{3/2}+bT^{3}$, within the experimental errors, in this region, with $a=3.3\times10^{-6}(°K)^{-3/2}$ and $b=0.9\times10^{-10}(°K)^{-3}$. By assuming the proportionality of the localized electron spin polarization to the spontaneous magnetization to be independent of temperature the foregoing result may be considered to be a confirmation of the applicability of the spin wave theory of ferromagnetism to cobalt. This situation is to be contrasted with the lack of agreement between experiment and theory for simple antiferromagnets. An upper limit of $10^{-3}(°K)^{-2}$ may be placed on the coefficient of the T^3 term predicted on the basis of an itinerant electron model for a ferromagnetic metal. The frequency for resonance extrapolated to $T=0°K$ is 217.4 Mc corresponding to an effective hyperfine field $H_{eff}=215$ koe. This is to be compared with the value $H_{eff}=216\pm4$ koe, obtained from specific heat measurements on bulk *hexagonal* cobalt, assuming the nuclear quadrupole interaction to be negligible.

[1] A. C. Gossard and A. M. Portis, Phys. Rev. Letters **3**, 164 (1959).

Q2. Jumping Rate of Deuterons between the Hydrogen Bonds of KD_2PO_4.* V. Hugo Schmidt and Edwin A. Uehling, *University of Washington.*—There are four principal lines in the magnetic resonance spectrum of deuterons in KD_2PO_4.[1] If one of these lines is saturated other lines are enhanced or saturated in a definite way. An effective exchange of deuterons between nonequivalent positions can cause the observed phenomena, but spin exchange cannot. The effective time τ_e of spatial exchange was measured directly using pulse methods. A value of about 0.4 sec was found for τ_e at 25°C. It decreases rapidly with increase in temperature, reaching a value of 0.015 sec at 70°C. The relaxation time T_1 decreases simultaneously by a factor of less than 2. The dependence of τ_e on temperature suggests barrier penetration with an activation energy of about 0.6 ev. The value found for τ_e, and failure of T_1 to change proportionally to τ_e, are not in accord with a relaxation model suggested previously,[1] based on deuteron jumps and the quadrupole interaction, from which the smaller value of $\tau_e=5\times10^{-3}$ sec was deduced.

* Supported by the Air Force Office of Scientific Research.
[1] J. L. Bjorkstam and E. A. Uehling, Phys. Rev. **114**, 961 (1959).

Q3. Carbon-13 Nuclear Magnetic Resonance Studies of Carbon Dioxide in Solution. Raymond Ettinger* and Andrew Patterson, Jr., *Yale University.*—To elucidate the behavior of carbon dioxide in aqueous solution, about which little is directly known, NMR studies were undertaken on the C^{13} isotope dissolved as CO_2 in various systems of varying concentration and gas pressure. The modified Bloch equations including chemical exchange have been applied with reasonable success. In uncatalyzed aqueous systems CO_2 is shown to be resolvable in dissolved and hydrated forms, but line broadening and signal collapse due to chemical exchange were observed when the relatively slow hydration process was accelerated with the efficient catalyst carbonic anhydrase. Because of experimental limitations, a resonance corresponding to carbonic acid has not yet been detected, but a maximum limit for its concentration has been determined from the sensitivity of the spectrometer employed and is consistent with present electrochemical estimates.[1] Since the spectra are necessarily recorded under rapid passage conditions in the dispersion mode, another exchange effect was noted: molecular transfer of nonequilibrium nuclear spin magnetization.[2] McConnell's analysis of the latter effect has also been applied to the CO_2 solution system. Chemical shift and relaxation time measurements are reported for carbon-containing species in various solvents.

* American Cyanamid Research Fellow, 1958–59. Present address: Rohm and Haas Company, Redstone Arsenal Research Division, Huntsville, Alabama.
[1] Wissbrun, French, and Patterson, J. Phys. Chem. **58**, 693 (1954).
[2] H. M. McConnell and D. D. Thompson, J. Chem. Phys. **31**, 85 (1959).

Q4. Free Precession Signal Decay in Presence of Ferromagnetic Grains. R. J. S. Brown, *California Research Corporation.*—Free precession signals were observed from fluid in samples containing randomly distributed ferromagnetic grains. The local free precession phase shift is calculated by computing volume of space *versus* strength of perturbing field near individual grains. The probability of a given phase shift from an individual grain is inversely proportional to the square of the phase shift, this being a limiting form of the Cauchy distribution. The resultant distribution of phase shifts from effects of many grains is then still of the Cauchy form. This leads to exponential signal decay, with the rate independent of diffusion effects. If M is the algebraic sum of the individual dipole moments of the magnetic grains, and γ the gyromagnetic ratio, $1/T_3=(8\pi^3/9\sqrt{3})M\gamma$ if all grains are magnetized parallel to the precession field; $1/T_2=(4\pi/3)M\gamma$ if perpendicular. Within 10%, $1/T_2=4.6M\gamma$ for any random or systematic orientation of the dipoles. Measurements on water containing magnetite powder stabilized by carboxymethylcellulose and on glycerine containing magnetite powder, as well as on sands containing magnetite and saturated with water or glycerine, verified the exponential decay, independence of decay rate on diffusion or viscosity, and the foregoing numerical value of decay rate (with small geometrical correction applied to sand system).

Q5. Electroacoustic Loss in Silicon and Germanium at 100 kc/s.* P. D. Southgate, *Armour Research Foundation* (introduced by J. W. Buttrey).—Measurements have been made of mechanical losses in germanium and silicon near 100 kc/s as a function of temperature. Around 0.56 of the melting point, a maximum in the internal friction occurs. The shift with frequency shows it to be a relaxation peak, while its temperature variation indicates that charge carriers are responsible. The relaxation time involved is the carrier lifetime, and the consistency of this time between specimens of differing purities is explained by the predominance of *intrinsic* recombination at higher temperatures. Analysis of the peak has been carried out using the theory of Weinreich.[1] The peak magnitude gives a value for change of band gap per unit dilational strain of 2.3 ev in silicon and 6.5 ev in germanium, near values derived by static measurements. The peak form can be fitted by an intrinsic lifetime varying as $T^{-3}\exp(E/kT)$, where $E=1.2$ ev in silicon and, less reliably, 1.15 ev in germanium. Measurements on specimens doped so that extrinsic recombination is important near the peak temperature show the expected modification of peak shape.

* Work performed at the Mullard Research Laboratories, Redhill, Surrey, England.
[1] G. Weinreich, Phys. Rev. **104**, 321 (1956).

Q6. NMR Acoustic Absorption in CsI^{127}, RbI^{127}, and NaI^{127}. M. Menes and D. I. Bolef, *Westinghouse Research Laboratories.*—NMR acoustic absorption was used to measure the quadrupolar coupling of the I^{127} nucleus in single crystal CsI, RbI, and NaI. The experimental method was similar to that described in a previous paper on KI and KBr.[1] Observed values of e^2qQ/h are: CsI^{127}, 1600 mc; RbI^{127}, 600 mc; NaI^{127}, 600 mc. The previously obtained value for KI^{127} is 300 mc. [The quantity q_1 is the derivative with respect to compressional strain in the (100) direction of the gradient of the electric field at the nuclear position.] Of the various models proposed to explain the quadrupolar coupling in ionic crystals, the one considering the slight covalent character of the ion orbitals seems the most suitable. The observed quadrupolar couplings correlate quite well with published values of the chemical shift for the same nuclei. In NaI, the covalent character of I^- is probably due to iodine-iodine overlap. Since in LiI the iodine-iodine distance is smaller than in NaI, we would expect a larger q_1 and chemical shift. A suitable sample for an acoustic absorption measurement on

LiI was not available, but we observed a value of chemical shift for LiI^{127} of 3.3×10^{-4} by conventional NMR methods.

[1] D. I. Bolef and M. Menes, Phys. Rev. 114, 1441 (1959).

Q7. Fermi Surface Information in Copper from Ultrasonic Attenuation.* J. D. GAVENDA† AND R. W. MORSE, *Brown University.*—For electron mean free paths longer than the ultrasonic wavelength (λ) there is an oscillatory variation of ultrasonic attenuation with magnetic field (H). These oscillations, which are periodic in H^{-1}, have been previously reported in a copper crystal at 4.2°K.[1] For H perpendicular to the propagation vector q the period of the oscillations should be determined by the extermal electron momentum mutually perpendicular to H and q. Thus, measurements of the periods as H is rotated about q in a single crystal should map out the Fermi surface in a plane perpendicular to q. Such measurements have been made at frequencies between 80 and 115 kc/sec with q along the [100], [110], and [111] directions. Results suggest that the surface touches the zone boundaries in [111] directions, as in Pippard's model.[2] A long period found when H is along [111] is consistent with orbits where electrons circle around the necks of the touching regions. These indicate that touching extends over about a 20° region.

* Supported by the Air Force Office of Scientific Research.
† Now at the University of Texas.
[1] R. W. Morse and J. D. Gavenda, Phys. Rev. Letters 2, 250 (1959).
[2] A. B. Pippard, Phil. Trans. Roy. Soc. (London) **A250**, 325 (1957).

Q8. Zero Field Magnetic Resonance of an X-Irradiated Organic Crystal, H. M. MCCONNELL, D. D. THOMPSON, AND R. W. FESSENDEN, *California Institute of Technology.*—Electron resonance has been observed in single crystals of x-irradiated malonic acid in zero applied field. X-ray damage to this crystal is known to produce the radical $CH(CO_2H)_2$ with a fixed orientation in the crystal lattice.[1] In this radical the only effective hyperfine interaction is between a single proton and a p-orbital electron distribution that is centered on a carbon atom. There are four nondegenerate eigenstates of the corresponding hyperfine Hamiltonian and transitions between these states are linearly polarized with frequencies that can be predicted from the observed high field paramagnetic resonance of the radical.[1] Two of the predicted transitions have been observed at 15.5±0.2 Mc and 13.4±0.2 Mc with the correct polarization. An rf bridge of a type commonly employed for nuclear magnetic resonance was used and the single crystal sample was at 77°K.

[1] McConnell, Heller, Cole, and Fessenden, J. Am. Chem. Soc. (to be published); Proc. Natl. Acad. Sci. 45, 525 (1959).

Q9. Photon Absorption by Valence Band Electrons in Nickel and Copper.* W. M. NEUPERT† AND D. H. TOMBOULIAN, *Cornell University.*—A normal incidence vacuum spectrograph having a dispersion of 4.26 A/mm has been used to measure the photon absorption by nickel and copper in the spectral region extending from 250 A to 800 A. This region corresponds to photon energies in the 50 ev to 15 ev range. The resolution at the high energy end is better than 0.1 ev. Measurements made on evaporated films (thickness 200 A to 300 A) indicate that fine structure exists on the low energy side of the $M_{2,3}$ absorption edge. Such structure represents photon absorption by valence electrons. For nickel, absorption maxima are found at 17.3, 18.7, 20.4, 22.0, 23.6, 25.4, 27.6, and 46.0 ev. For copper, absorption maxima are found at 17.1, 20.0, 21.8, 23.3, 25.8, and 35.0 ev. These results will be compared with x-ray fine structure data and electron energy eigenlosses. A model for the observed absorption spectra in terms of one-electron transitions from the $3d$ valence band will be presented.

* Supported by the Office of Ordnance Research, U. S. Army.
† Now at University of California at Santa Barbara.

Q10. Observation of Domains of Reversed Magnetization in Iron Whiskers.* C. A. FOWLER, JR., E. M. FRYER, AND D. TREVES,† *Pomona College.*—Domains of reversed magnetization in iron whiskers subjected to relatively high magnetic fields have been observed with the Kerr magneto-optic technique. The apparatus employed was a refined version of that previously described,[1] permitting improved resolution. In iron whiskers of width 100 μ or less, reversal domains have been observed even under fields considerably greater than those usually considered necessary to produce saturation. These domains extend back from the tip of the whisker and appear to retreat toward the tip as the field is increased. They have been followed observationally to fields of 200 oe where their size reaches the present limit of resolution of the apparatus. In configuration and behavior the reversal domains are very similar to those theoretically predicted for high fields by Shtrikman and Treves,[2] who have suggested that their nucleation is caused by the strong demagnetizing fields existing at the sharp corners of saturated crystal samples.

* Supported by the Office of Naval Research.
† On leave from the Weizmann Institute of Science, Rehovot, Israel.
[1] C. A. Fowler, Jr., and E. M. Fryer, Phys. Rev. 94, 52 (1954).
[2] S. Shtrikman and D. Treves, Magnetism and Magnetics Materials Conference, Detroit (November, 1959), contributed paper.

Q11. Elastic Moduli of Single-Crystal Rutile (TiO_2). GERALD L. VICK, LEWIS E. HOLLANDER, AND A. E. BROWN, *Lockheed Missiles and Space Division.*—Four of the six elastic moduli, C_{11}, C_{33}, C_{44}, and C_{66}, of rutile have been determined by a 10 mc ultrasonic pulse technique. The remaining two C_{12} and C_{13} have been determined by combining ultrasonic pulse data and Bridgman's compressibility data.[1] The results are: $C_{11}=2.8\pm0.3$, $C_{33}=4.6\pm0.4$, $C_{12}=1.8\pm0.2$, $C_{13}=1.4\pm0.2$, $C_{44}=1.2\pm0.1$, and $C_{66}=1.6\pm0.2$; all in units of 10^{12} dynes/cm^2. Good agreement is obtained with the values computed from Raman spectra and infrared data by Dayal and Appalanarasimham,[2] except in the case of C_{33} for which these authors report a value of 1.9×10^{12} dynes/cm^2. However, only nearest-neighbor interactions were considered in their analysis. C_{33} was also measured in oxygen-deficient rutile, having a resistivity of 10^{-1} ohm cm. No change within the limits indicated was observed, but the acoustic attenuation was greatly increased. The attenuation is also much greater in the [100] than in the [001] crystal direction in both reduced and oxidized rutile.

[1] Quoted by F. A. Grant, Revs. Modern Phys. 31, 646 (1959).
[2] B. Dayal and N. Appalanarasimham, J. Sci. Research Benares Hindu Univ. 1, 26 (1950).

Q12. Effect of Strain on Conduction in Reduced Single-Crystal Rutile (TiO_2). LEWIS E. HOLLANDER, T. J. DIESEL,* AND GERALD L. VICK, *Lockheed Missiles and Space Division.*—Single-crystal samples of rutile in the resistivity range 10^{-1} to 10^3 ohm cm were prepared by reduction in hydrogen at temperatures above 450°C, producing nonstoichiometric compositions of TiO_2. This process is completely reversible and the tetragonal rutile structure is maintained.[1] The effects of longitudinal, transverse, shear, and hydrostatic strains on the conduction of these samples was determined. The piezoresistive coefficients π_{ijkl} for rutile are presented for various states of oxygen deficiency. The longitudinal piezoresistive coefficients along the crystal axis in the "c" direction π_{33} is +7.9 at 65 ohm-cm and *diminishes* with an *increase* in the density of oxygen vacancies to +0.7 at 0.17 ohm-cm. In the "a" direction π_{11} is +0.6 at 930 ohm-cm and *increases* with an *increase* in the density of oxygen vacancies to +10.2 at 0.28 ohm-cm. The units of all π coefficients are 10^{-12} cm^2/dyne. These results suggest that there is strong orbital overlap of the impurity wave functions in the c direction, while in contrast in the a direction this overlap seems to be

appreciable only at 10^{-1} ohm-cm and diminishes above 1 ohm-cm.

* Department of Physics, University of Colorado.
[1] F. A. Grant, Revs. Modern Phys. 31, 646 (1959).

Q13. Effect of γ Irradiation on Young's Modulus and Internal Friction in Sapphire.* L. L. BIENVENUE AND C. E. DIXON, *Atomics International.*—Young's modulus and internal friction measurements were made in single crystal Al_2O_3 as a function of Co^{60} γ irradiation. Young's modulus decreased 0.7% to a minimum at 2×10^{15} photons/cm^2; subsequent radiation resulted in a slower increase which saturated at 5×10^{15} photons/cm^2, 0.6% below the original value. The internal friction (Q^{-1}) increased from 10^{-5} to a maximum of 7×10^{-5} at 2×10^{15} photons/cm^2 and decreased slowly to its original value at 6×10^{16} photons/cm^2. These effects up to 2×10^{15} photons/cm^2 are just the opposite of those observed in metals. A mechanism for irradiation-induced unpinning of dislocations is required to explain the present low flux results.

* Supported by the U. S. Atomic Energy Commission.

Q14. Displacement Thresholds in InSb.* F. H. EISEN, *Atomics International.*—In *n*-type InSb (1.5×10^{16} carriers/cm^3) damage produced by 1 Mev electron irradiation recovers in five stages centered at 90°K, 150°K, 175°K, 210°K, and 275°K, respectively. The fraction of recovery occurring in a particular stage is independent of the integrated exposure for a variation in exposure of at least a factor of 15. Measurement of the damage recovering in each stage as a function of bombarding electron energy suggests that there are at least three and possibly five thresholds for production of the damage recovering in each of the stages. Damage recovering in the first two stages is produced at energies as low as 240 kev. The production of damage in the higher temperature stages increases rapidly at electron energies between 500 and 600 kev. The results suggest that, with a detailed interpretation of the recovery kinetics, one may be able to assign threshold energies for the displacement of atoms to different stable interstitial positions in InSb.

* Supported by the U. S. Atomic Energy Commission.

Q15. Rule of Simple Multiple Relations of Masses As Applied to the Composition of Isomorphous Compounds of Crystalline Matter. N. EFREMOV, *New York.*—The crystallization processes in magmatic silicate melts are characterized by the rule of simple multiple relations of masses. The tendency to achieve simple multiple relations (2:1, 3:2, 1:1, etc.) between the collective mass (sum of atomic weights) of all metals (e.g., Mg, Ca, Fe, Al, and also H) and the mass (atomic weight) of silicon is illustrated by the isomorphous substitution of host ions in the crystalline lattices of minerals by some other ions (e.g., magnesiasilicates, where bivalent $Mg^{\cdot\cdot}$ ions are replaced by bivalent $Fe^{\cdot\cdot}$ ions, alumosilicates-plagioclases, where the pentavalent complex of $Na^{\cdot}Si^{\cdot\cdot\cdot\cdot}$ ions is substituted by pentavalent complex of $Ca^{\cdot\cdot}Al^{\cdot\cdot\cdot}$ ions, etc.). The simplest relation, 1:1, between the collective mass of metals and the mass of silicon is found in the chemical composition of the most abundant rock-forming silicates, such as alumosilicates-plagioclases which constitute the chief mass of the earth's crust, e.g.,

Plagioclase-andesin	Relations of atomic weights
$NaAlSi_2O_8 \cdot CaAl_2Si_2O_8$	$(NaAl+CaAl_2):5Si=1,02:1.$

The aforementioned regularity for the first time makes it possible to explain the so-called "anomaly in the chemical composition" of alumosilicates-plagioclases.[1]

[1] S. H. Washington and G. F. Wright, Am. J. Sci. Ser. 4, 178, 180, (1910).

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Fowler, W. A.—D1, P13
Fox, Raymond—G3
Fryer, E. M.—Q10
Gallagher, J. J.—J11
Gavenda, J. D.—Q7
Gettner, M.—F6
Goetzberger, Adolf—J12, J13
Goles, Gordon G.—G11
Goodwin, Lester K.—F5
Gove, H. E.—C10, M4
Greenstein, J. L.—D4
Gursky, Martin L.—P11
Haddock, Roy P.—F4
Hammond, Robert H.—I8
Hartman, C. W.—J4
Hauser, U.—P5
Hausman, H. J.—C11
Heller, Leon—P11
Helmy, E.—F13
Henke, Burton L.—J7
Hershberger, W. D.—G1
Hollander, Lewis E.—Q11, Q12
Hori, H.—N7
Horwitz, Nahmin—F9
Hoyle, F.—A3
Hubner, K.—J14
Hull, T. E.—P13
Jaccarino, V.—Q1
Jeffries, C. D.—I11, I12
Johnston, W. H.—P1
Jorgensen, T., Jr.—J1
Kaplan, Selig—F3
Kauffman, J. W.—J16
Kavanagh, R. W.—C2, C4
Kellogg, Paul J.—G2
Kenney, Robert W.—F5
Kleinman, Leonard—N4
Knight, W. D.—I8
Koehler, T.—B4
Kuyatt, C. E.—J1
Lang, W. W.—J1
Latter, R.—K5
Leifson, O. S.—I11, I12
Leinbach, H.—O1
Lidofsky, L. J.—M3
Liemohn, Harold—G2
Litherland, A. E.—C10
Macdonald, Burns—F3
Maeda, Kaichi—G10
Maglić, B.—F7, F8, P8
Marrus, R.—I3
Martinelli, E. A.—K4
Mason, Conrad J.—F10
Mathews, Jon—F2
Mattis, D. C.—I7
Mayer, J. W.—N1
McClelland, J. D.—N10
McConnell, H. M.—Q8
McDaniels, D. K.—C12
McDonald, Bruce—J13
Meechan, C. J.—N8
Melkanoff, M.—F12
Menes, M.—Q6
Mercereau, J.—B3
Meshii, M.—J16
Meyer, P.—O4
Miller, A. E.—C16
Miller, Donald—F9
Minkowski, R. L.—A2
Mori, T.—J16
Morisky, T. F.—J3
Morse, R. W.—Q7
Murray, Joseph—F9
Neddermeyer, S. H.—F16, N12
Neupert, W. M.—Q9
Ney, E. P.—O3
Nickols, Norris A.—F10
Nierenberg, W. A.—I3, I5
Nordberg, Emery—N3
Olbert, S.—H4
Osgood, C. F.—C3
Overley, J. C.—C5
Parker, P. D.—C2
Parks, J.—F8
Patterson, Andrew, Jr.—Q3
Perez-Mendez, Victor—F5, H1
Perlman, I.—P15
Perry, R. L.—J3
Petersen, F. R.—I4, I6
Phillips, James C.—N4
Pincus, P.—I9
Powers, Darden—C14
Press, F.—K3
Prowse, D. J.—C13, F11, F12, F13
Pyle, Robert V.—F3
Rachal, L.—N9
Rasmussen, J. O.—P15
Raymo, C. T.—N5
Retz-Schmidt, Theo—C8
Richardson, J. Reginald—P2
Roberts, J. A.—A1
Robinson, D.—G7
Rogers, Ernest—F1
Romney, C.—K2
Rosen, A.—E1
Roth, H.—N2, N6
Rouse, Carl A.—G4
Salmon, G. L.—C6, C7
Samson, J. A. R.—G7, J5, J6
Sandage, A.—D5
Sanders, N. L.—P4
Sautter, C. A.—J1
Schein, M.—H5
Schmidt, M.—A4
Schmidt, V. Hugo—Q2
Schwartz, B.—N5
Schweizer, Felix—P2
Scott, P. L.—I11, I12
Seagrave, John D.—C1
Seeger, Philip A.—P12
Segel, R. E.—C6, C7
Selove, W.—F6
Serbin, Hyman—G12
Shockley, William—J12, J14
Shugart, H. A.—I4, I6
Shulman, R. G.—I2
Simpson, J. A.—I.2

Slawecki, T. K.—G8
Sloan, D. H.—J4
Smith, Felix T.—P10
Smith, Frances M.—F10
Snyder, C. W.—L1
Solmitz, F. T.—H2
Sonett, C. P.—L3
Soohoo, R. F.—I10
Soshea, R. W.—J2
Sosin, A.—N9
Southgate, P. D.—Q5
Stein, W. E.—P6
Stephens, Charles—J13
Stevenson, Mirek J.—I13
Stierwalt, Donald L.—J15
Stork, D. H.—F12, F13
Suess, H. E.—L5
Sundaram, S.—J10
Tewes, H. A.—C16
Thompson, D. D.—Q8
Thompson, S. G.—P15
Thyagarajan, G.—J10
Tinkham, M.—B1
Tochilin, E.—C15
Tomboulian, D. H.—Q9
Trainor, L. E. H.—F14
Treves, D.—Q10
Uehling, Edwin A.—Q2
Urey, H. C.—L4
Van Heerden, I. J.—C13
van Lint, V. A. J.—N2, N6
Vick, Gerald L.—Q11, Q12
Wasserburg, G. J.—D2
Watanabe, S.—P7
Weil, Jesse L.—C8
Weissler, G. L.—G7
Wells, D. O.—P3
Whetstone, S. L., Jr.—P6
Wikner, E. G.—N2, N6
Wilets, L.—P9
Wilson, O. C.—D3
Wilson, Ralph A., Jr.—J9
Winckler, J. R.—O2
Winocur, J.—I3
Woodruff, Wayne R.—G5

Preliminary Announcement of the 1960 Annual Meeting

The 1960 Annual Meeting of the American Physical Society will be held in New York City, on Wednesday, Thursday, Friday, and Saturday, January 27, 28, 29, and 30. As usual, the American Association of Physics Teachers will hold concurrent sessions, and there will be a joint ceremonial session of the two societies comprising our Retiring Presidential Address, and the Richtmyer lecture and the Oersted Prize presentation of AAPT. There will be a Business Meeting of our Society. Also, as usual, the official hotel will be the New Yorker (New York 1, New York). It is not too early to make your reservations; in writing to the hotel mention that you are coming to a meeting of this Society. The scientific sessions will be held in or near the New Yorker.

Deadline day is November 13, and abstracts are to be sent to Karl K. Darrow, American Physical Society, Columbia University, New York 27, New York.

Preliminary Announcement of the 1960 Southwestern Meeting

In 1960 the Southwestern Meeting of the Society returns to its first home, The Rice Institute at Houston, Texas. The dates will be Friday and Saturday, March 4 and 5. The hotels that have set aside rooms for our members are the Shamrock-Hilton and the Warwick, both close to the campus of The Rice Institute. In writing to these, be sure to mention that you are coming to the meeting of the American Physical Society.

Deadline day is Friday, January 8, and abstracts are to be sent to Karl K. Darrow, American Physical Society, Columbia University, New York 27, New York. *Please be careful to mark your abstracts for the Southwestern Meeting, as deadline for the Detroit Meeting arrives only a week later.*

Preliminary Announcement of the 1960 "March" Meeting

The 1960 "March" Meeting of the American Physical Society—so called because we have never yet been able to discover a short way of saying "the meeting which is devoted mainly to the Divisions of High-Polymer Physics, Solid-State Physics, and Chemical Physics"—will be held in Detroit, Michigan, on Monday, Tuesday, Wednesday, and Thursday, March 21–24. The Division of High-Polymer Physics expects to meet from Tuesday through Thursday; the others will begin on Monday and may (or may not) confine their papers to three days. The hotels which have set aside rooms for our members are the Park-Shelton, the Statler, and the Sheraton-Cadillac. In writing to any of these, be sure to mention that you are coming to the meeting of the American Physical Society.

Deadline-day is Friday, January 15, and abstracts are to be sent to Karl K. Darrow, American Physical Society, Columbia University, New York 27, New York. *Please be careful to mark your abstracts for the Detroit Meeting, as deadline for the Southwestern Meeting arrives only one week earlier.*

1960 Conference on Reactions between Complex Nuclei

A second conference on Reactions between Complex Nuclei will be held on May 2 and 3, 1960, at Gatlinburg, Tennessee. Any member of the Society who desires more detailed information should write to Dr. R. S. Livingston, Oak Ridge National Laboratory, Oak Ridge, Tennessee. Abstracts of contributed papers may be sent to Dr. Livingston (*not to the Secretary of the Society!*) and must reach him not later than April 2, 1960. Take note that it is the prerogative of the management of the Conference to accept or decline contributed papers that are offered.

MEETINGS AND DEADLINES THROUGH JUNE, 1960

Place	*Meeting dates*	*Deadline date*
Cleveland	November 27–28, 1959	past
Pasadena*	December 28–30, 1959	past
New York	January 27–30, 1960	November 13
Houston	March 4–5, 1960	January 8
Detroit	March 21–24, 1960	January 15
Washington	April 25–28, 1960	February 12
Montreal	June 15–17, 1960	April 8

* Abstracts for the Pasadena meeting are to be sent to W. A. NIERENBERG, University of California, Berkeley 4, California, and must reach his office not later than the corresponding deadline date. Abstracts for topical conferences are to be sent to the addresses given on page 433.

Abstracts for the other meetings listed above are to be sent to KARL K. DARROW, American Physical Society, Columbia University, New York 27, New York, and must reach his office not later than the corresponding deadline date. Take note that abstracts mailed the day before deadline day often fail to arrive in time: the last postal delivery of the day usually comes to our office before 2 P.M. Allow at least two days for abstracts sent by airmail from points east of the Mississippi, and longer for those sent from farther west. Abstracts postmarked (at the point of dispatch) on deadline day are instantly rejected, and telegrams heralding their arrival are fruitless except in revenue to the telegraph company. *The privilege of contributing papers to meetings of the American Physical Society is restricted to the members of the Society and to nonmembers whose papers are sponsored by members.*

TOPICAL CONFERENCES (see above)

Gatlinburg	Reactions between Complex Nuclei	May 2–3, 1960	April 2

RULES AND INSTRUCTIONS FOR THE PREPARATION OF ABSTRACTS

The Council has ordered that abstracts shall be not longer than two hundred (200) words or the equivalent thereof. In reckoning equivalence, a footnote is equated to ten words (*but see new instruction below!*); each line in a table to ten words; a "display" formula—one that requires a line to itself—is an expensive luxury equated to forty words.

Two copies of each abstract must be sent to the appropriate office. They must be typewritten; *one must be an original,* the other may be an original or a carbon copy. *Carbon copies will not be accepted in lieu of originals:* they smear. *Abstracts must be double-spaced:* single-spaced manuscripts are too crowded to permit the editorial markings to be made with ease and clearness. *Each abstract must be confined to a single page:* if it is too long for a single page it is too long to be printed. If we receive an abstract typed on two pages, we print only its first page. *Write each abstract as a single paragraph:* the suppression of paragraphs costs time and labor to the editors. *Do not use very thin paper:* a sheet of very thin paper may cause extraordinary trouble when mixed with sheets of reasonable thickness. The American Institute of Physics will bless you if you type first the title of your abstract in lower-case with capitalized initials, then your name in capitals, then the name of your institution in lower-case underlined with capitalized initials. It is a pleasure to report that those who qualify for this blessing are increasing in number but are still quite a bit short of 100% of the total. Issues of the *Bulletin* are always appreciably delayed because the editors have to do what the authors should have done.

Remember the rule of the Council that, if an author submits more than one abstract, all but one must go onto the Supplementary Programme. In enforcing this rule, an abstract is credited to the author whose name appears first in the by-line.

It has now become an expensive business to make any change in an abstract, even the smallest, after the abstract has gone to press. By order of our Council "A change in an abstract will be permitted only at the discretion of the Secretary or his deputy, and only if TEN DOLLARS is enclosed with the letter in which the change is requested." As heretofore, an abstract will not be withdrawn from proof unless the asker sends ten dollars with his request.

New Instructions

(a) If it is wished that two abstracts be scheduled consecutively, write on the first "To be scheduled before abstract ..... by ....." and on the second "To be scheduled after abstract ..... by ....."

(b) If a member insists that his paper be scheduled for a particular day or not on a particular day, he will get his wish, but usually at the price of having his contribution included in a session to which it is irrelevant.

(c) The Secretary and his deputies have been empowered by the Council to count a footnote either as ten words or as its actual length in words, whichever is the greater length.

Proceedings of the American Physical Society

Minutes of the Fall Meeting of the Ohio Section of The American Physical Society, Held at Kent State University, Kent, Ohio, on October 16–17, 1959

THE regular fall meeting of the Ohio Section of The American Physical Society was held on Friday and Saturday, October 16–17, 1959, at Kent State University, Kent, Ohio.

On Friday morning, October 16, Dr. Maurice Horowitz and his colleagues at the Goodyear Aircraft Corporation, arranged an excellent tour of the Corporation's facilities at the edge of Akron, Ohio. The fifteen or so men who were able to get to the Goodyear Aircraft Corporation plant, were shown the large antennae, and the various types of antennae under test and under construction for various purposes. The time was early for those who had to travel across the state so the number was smaller than it would otherwise have been. The Section is very appreciative of this and other trips that have been arranged for it.

Kent State University is noting its fiftieth year; thus the University is doing as many other universities now do, supporting many varied activities on its campus. They helped Dr. George K. Schoepfle and his staff financially so that our Section could in part pay an honorarium to an invited speaker. We secured Dr. R. V. Pound of Harvard University, for our invited speaker. He spoke on Friday on the subject "Thermally Excited Molecular Motion," and on Saturday morning Dr. Pound talked on "Spin Temperatures."

After Dr. Pound's talk on Friday, the Section enjoyed a coffee break due to the kindness of the Student Section of the American Institute of Physics at Kent State University. The attendance at both sessions was about 80, some coming for the Saturday session who could not come for Friday. A few who appeared Friday could not be present on Saturday. Nine contributed papers were presented —four on Friday afternoon and five on Saturday morning. The abstracts of the contributed papers follow.

Leon E. Smith, *Secretary Ohio Section*
Denison University
Granville, Ohio

1. Amplifiers and Antennas for Long Range Systems. M. Horowitz, L. A. Zurcher, and G. A. Biecker, *Goodyear Aircraft Corporation.*—There is a continuing requirement for extending the range of radar and communications systems. One method of meeting this requirement is the use of large aperture antennas and very low noise receivers. This paper presents an analysis of such a system with the object of predicting the over-all performance in terms of effective noise temperature. The system effective noise temperature is related to the losses, gains, and effective noise temperatures of the individual noise networks. A graphical summary of present and expected effective noise temperatures for quantum-mechanical and parametric amplifiers compared with those for conventional devices is given. The conversion between noise figure and effective noise temperature is given. The contribution of large aperture antennas to the system effective noise temperature is discussed and a summary of antenna temperatures in certain typical cases is given. A motion picture is exhibited showing structural details of large antennas which have been fabricated.

2. Solid State Radio Frequency Amplifiers. D. C. Lewis, *Goodyear Aircraft Corporation* (introduced by M. Horowitz).—Recent developments in high-frequency transistors and variable reactance diodes for parametric amplifiers make low noise solid-state receivers possible. Radio frequency and intermediate frequency amplifiers will be considered. A prototype very high-frequency parametric amplifier and a 60 mc transistor intermediate frequency amplifier will be exhibited. The exhibit will be accompanied by a short review of operating principles and a discussion of the prototype circuits.

3. Construction of a Cavity Maser. K. R. Colling and M. Horowitz, *Goodyear Aircraft Corporation.*—A cavity maser is under construction. The system uses a crystal of $K_3Co_{0.995}Cr_{0.005}(CN)_6$ in a coaxial cavity. This cavity, with suitable coupling devices, provides the required electromagnetic fields for maser action. The cavity will be immersed in a liquid helium bath. The Dewar system is capable of being pumped to obtain temperatures down to 1°K. A 12-in. Varian electromagnet will be used for the external magnetic field. The entire system will be operated in a double shield screen room.

4. Momentum along Lines of *B*? Albert B. Stewart, *Antioch College.*—A number of experiments (unpublished results) have been performed in an attempt to find a component of momentum along the lines of magnetic flux density *B*. The experiments are of two types: (a) torsion experiments to detect the momentum transferred from a circuit to a magnetic field and (b) experiments to detect a difference in the speed of light traveling with and against a magnetic field. The experiments will be described and it will be shown that the special theory of relativity predicts a null effect for each one. Further, a positive result for any one of the experiments would indicate a lack of mirror symmetry, i.e., nonconservation of parity, for electromagnetism.

5. Statistical Treatment of Laboratory Data for Beginning Scientists and Engineers. Philip A. Macklin, *Miami University.*—In order to equip scientists and engineers with essentially correct statistical tools and methods, rather than introducing techniques which must later be unlearned or revised, we have incorporated standard derivation calculations into the laboratory work in the first course in physics for scientists and engineers. Using the least count of the measuring instrument as a simple, albeit approximate, estimate of the standard deviation of a measurement, and using propagation of error expressions for simple functions (sums, differences, products, quotients, powers, averages, etc.), all results are

formulated as $\bar{x} \pm s(\bar{x})$; thus allowing objective answers to questions such as agreement of different results, etc. After the calculus has been introduced, the general case for the standard deviation $s(y)$ of a function y of n statistically independent variables x_i is derived. From this, all previous cases of simple functions are obtained, as well as more complicated cases. Experience during the last three years encourages us to feel that such an approach is both feasible and desirable.

6. Bumper-to-Bumper Traffic Dynamics. S. MACHLUP, *Western Reserve University.*—The problem of choosing the speed and spacing of cars such as to maximize the flux on a "full" highway may be approached by (1) assuming a "safety condition" relating the minimum spacing to the speed, (2) maximizing the flux subject to this condition, and then (3) checking whether this steady-state solution is stable against small velocity perturbations, i.e., whether such perturbations are damped out rather than propagating backward along the line of cars with increasing amplitude to become a shock wave.[1] (1) An "absolute safety condition" is that the distance d between cars moving at speed v be greater than the distance vT the cars goes in the driver's reaction time T, plus the braking distance $v^2/2a$, where $-a$ is the braking acceleration. (2) For cars of length L, the flux $v/(d+L)$ is then maximized when $v=(2aL)^{\frac{1}{2}}$=speed for which the braking distance is equal to the car length. (3) The "absolute safety condition" turns out to be exactly the condition for attenuation of perturbation waves. Comparison with data on traffic in tunnels lends some support to this elementary model.[2]

[1] R. Courant and K. O. Friedrich, *Supersonic Flow and Shock Waves* (Interscience Publishers, Inc., New York, 1948), Sec. 58; M. J. Lighthill and G. B. Whitham, Proc. Roy. Soc. (London) **A229**, 317–345 (1955); P. I. Richards, Operations Research **4**, 42–51 (1956).
[2] Edward S. Olcott, Operations Research **3**, 146–167 (1955).

7. Molecular Motion in Solids. Proton Magnetic Resonance of Some Sandwich Type Organo Metallic Compounds.* L. N. MULAY, *University of Cincinnati* AND E. G. ROCHOW, N. E. WELIKY, AND E. O. STEJSKAL, *Harvard University.*—Broad line proton magnetic resonance absorption has been studied in ferrocene and its derivatives as a function of temperature. The latter give broader lines with higher second moments than those observed for ferrocene. This has been interpreted in terms of the slowing down of the motion of cyclopentadienyl ring (s) resulting from substitution in one or both rings. This trend is found to depend on the size of the substituent and to increase with substitution in both rings which favors a freezing of motion more readily than ferrocene. The bridged (α Keto-trimethylene) ferrocene gives in general a very broad line ($\delta H=12.7$ gauss) with a high second moment (9 gauss^2) suggesting absence of free rotation of the rings. Ferrocene itself gives (as reported before[1]) a "liquid-like" line about 4 gauss wide. A comparison of its second moment S in gauss^2 (2.8 ± 0.5) with the theoretically calculated values for the following models shows agreement with (b) and places the concept of rotation of rings on a sound basis: (a) No motion ($S\sim8$); (b) Rotation about fivefold symmetry axis (with or without internal motion) ($S\sim2$–3.5); (c) free reorientation about all axes ($S\sim1$–2).

* Work supported at University of Cincinnati by grants from Research Corporation and Monsanto, and at Harvard University by ONR.
[1] J. Inorg. & Nuclear Chem. **4**, 231 (1957).

8. Proton Magnetic Resonance Study of the Monohydrates of Potassium Mercuric Chloride and Potassium Stannous Chloride.* A. A. SILVIDI AND J. W. MCGRATH, *Kent State University.*—A proton magnetic resonance study has been made of the monohydrates of potassium mercuric chloride and potassium stannous chloride using a slightly modified Pound-Watkins spectrometer. The results for the mercuric salt are that there are two orientations of the p-p axes lying in the crystallographic ab plane and making angles of $\pm20°33'$ with the a axis. The average values of both of the p-p separations are 1.59 ± 0.01 A. The results for the tin salt are that there are two orientations of the p-p axes lying in the crystallographic ab plane and making angles of $\pm38°10'$ with the a axis. The average values of both of the p-p separations are 1.59 ± 0.01 A. The method of obtaining these values will be briefly explained. The results will be compared with the previously published information[1] on these compounds.

* Partially supported by the U. S. Air Force through the Air Force Office of Scientific Research.
[1] Itoh, Kusaka, Yamagata, Kiriyama, Ibamoto, Kanda, and Masuda, J. Phys. Soc. Japan **8**, No. 3 (1953).

9. Effective Interatomic Potential for the Excitation Spectrum of Liquid He II.* R. T. WHITLOCK AND E. H. SYNN. *Western Reserve University* (introduced by P. R. Zilsel).—Bogoliubov's[1] expression for the excitation spectrum of a dilute Bose system with weak interaction was shown[2] to be approximately applicable to liquid helium II if the Fourier transform V_k of the interaction potential between two atoms is replaced by that of a potential cutoff to take into account the reduced effectiveness of the repulsive core. The exact form of the cutoff to be used is unknown, but may be specified in terms of two parameters, the cutoff radius r_0 and the steepness α. We have computed the spectrum for various values of these parameters, chosen so as to give the correct behavior in the low-k (phonon) limit. Semi-quantitative agreement with experiment can be obtained for reasonable values of the parameters. In particular, a pronounced "roton" minimum appears at the experimental value of $k_0=1.95\times10^8$ cm^{-1} for all "steep cutoffs," independently of the exact value of α.

* This research was supported in part by the U. S. Army Office of Ordnance Research.
[1] N. N. Bogoliubov and D. N. Zubarev, Soviet Phys. JETP **1**, 83 (1955).
[2] P. R. Zilsel, *Proceedings of the Stevens Institute Conference on the Many-Body Problem* (Interscience Publishers, Inc., New York, to be published).

Abstracts of Papers Presented at the Topical Conference on Neutron Capture Reactions at Los Alamos, New Mexico, October 1–3, 1959

A2. Fluctuations in Partial Radiation Widths. J. R. Bird and J. E. Lynn, *A.E.R.E., Harwell.*—Recent results will be described of measurements of the γ-ray spectra from resonant neutron capture in heavy elements which have been made using the 15-Mev Harwell electron linear accelerator. These results, together with those of other recent experiments, show fluctuations in the intensities of individual γ rays. The nature of these fluctuations will be discussed in relation to the difficulty involved in making these measurements and the results will be analyzed in terms of a chi-squared distribution.

A3. Measurements of Widths for Individual Radiative Transitions from Resonant Neutron Capture.* R. E. Coté, T. J. Kennett, and L. M. Bollinger, *Argonne National Laboratory.*—The Argonne fast chopper is being used in a series of measurements of gamma-ray spectra from resonant neutron capture. One objective of these studies is to determine the distribution of the widths of high-energy radiative transitions to a single final state from the many closely spaced initial states formed by resonant capture. Calculations reveal that the measured distribution in widths depends in a crucial way on an ability to observe exceedingly weak (probability $<0.1\%$) transitions. The techniques developed to attain this objective were applied to a measurement of probabilities of transitions to the ground state and to the first excited states of the even-even nuclides formed by capture in the spin $\frac{1}{2}^-$ target nuclides W^{183}, Pt^{195}, and Hg^{199}. The results obtained are compared with those of other experimenters, with W^{184} being a particularly interesting case. For this nuclide the data of the Brookhaven group have been interpreted as showing that the partial radiation widths fluctuate only slightly. We obtain a result that is consistent with these data if we consider the *sum* $(\Gamma_0+\Gamma_1)$ of transitions to the ground state and the first excited state.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

A4. Distribution of Widths for Individual Radiative Transition.* L. M. Bollinger, T. J. Kennett, and R. E. Coté, *Argonne National Laboratory.*—The results of the measurements of widths for individual radiative transitions are analyzed from the viewpoint of obtaining quantitative information about the distribution of widths for high-energy transitions to a single final state from the many closely spaced states of the same J value resulting from resonant capture. The first step is to use the gamma-ray spectra as a tool to assign J values to the resonances studied. These assignments result in requiring 20 experimental widths to be for $E1$ transitions. The widths are treated under the assumption that they satisfy a χ^2-distribution with ν degrees of freedom, where ν is a parameter to be extracted from the data. A modification of the method of maximum likelihood is used in the analysis. Preliminary calculations indicate with high probability that $1<\nu<5$. The important theoretical question of whether the data are consistent with a Porter-Thomas distribution ($x^{-\frac{1}{2}}e^{-x/2}$) was answered by a Monte Carlo calculation which allowed us to take into account the unavoidable bias introduced by an inability to observe very weak transitions. Assuming the experimental data to be a sample drawn from a population having $\nu=1$, we find a 30% probability that the measured value of ν could be greater than the value obtained from the experimental data.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

A5. Intermediate Neutron Capture Resonances of Spin $J=1$ in Tungsten and Platinum. J. M. Julien, C. R. Corge, V. D. Huynh, S. U. Mirza, F. Netter, and J. Simic, *Centre d'Etudes Nucleaires de Saclay* (introduced by E. Cotton).—The Saclay 28-Mev linear accelerator and associated time-of-flight equipment have been used to determine the spins of some of the intermediate neutron resonances in tungsten and platinum.[1] This has been done by investigating the neutron capture γ rays with a single channel analyzer set on low and high energies. The duration of neutron burst and the timing channels were 0.5 μsec each. The flight path was 53.81 m long. The spin value $J=1$ has been assigned to the following levels: W^{184} −7.62, 27.1, 40.8, 46.6, 65.7, 157.5, 174.5, 184.7, 193, 216, 244.5, 259.5, 297.5, 323, 362, 543, 696, 759, 801, 961, 1096, 1135, 1415, and 1515 ev; Pt^{196} −69, 120.5, 140, 150.8, 155, 189, 223, 286, 304, 412, 455, 492, 561, 606, 682, 710, 828, 853, 1092, 1260, 1330, and 1470 ev. The transition probabilities of the ground state γ rays show some large variations from level to level.

[1] C. Corge *et al.*, Compt. rend. 249, 413 (1959).

A6. Gamma Rays from Resonance Neutron Capture.* Morton K. Brussel and Robert L. Zimmerman, *Brookhaven National Laboratory.*—Using apparatus described in an adjoining abstract we have measured high energy γ-ray transition probabilities from resonances in Pt and Hg relative to given standardizing resonances in those nuclides. This is done by measuring the ratio of the number of γ rays emitted from a target directly to the ground state of the product nucleus to the number of γ rays emitted in some lower energy region. Comparing this ratio for any given capturing resonance to that for a given "standard" resonance, one can obtain the ratio of the partial radiation widths to the ground state appropriate to those resonances. One assumes here that the total radiation width is constant from level to level, and that the γ-ray multiplicities and spectra are reasonably constant. We have analyzed 13 resonances in Pt^{195} from neutron energy 11 to 300 ev. All but three of these are assigned spin $J=1$. Two resonances at 258 ev and 203 ev are $J=0$ and one at 155 ev is possibly $J=0$. We have determined which χ^2 distribution best fits our data using the maximum likelihood type of analysis, we find that for 13 resonances (with those at 258 and 203 ev as $J=0$) we get $\nu=5.5_{1.5}{}^{+4}$ for the number of degrees of freedom and $\nu=7.5_{-2}{}^{+6}$ with the 155-ev level taken as $J=0$.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

A7. Brookhaven Resonance Capture Gamma-Ray Apparatus.* H. Palevsky and J. Fox, *Brookhaven National Laboratory.*—The Brookhaven apparatus for the study of capture γ rays from individual neutron resonance levels consists of six 3-in.×3-in. thick NaI(Tl) crystals surrounding the perimeter of a 3-in.×6-in. sample. The solid angle subtended by the sample at the counter is about 10%. The signals from the six preselected photomultipliers are fed into a fast transistor mixing circuit which has a gain of about 5 and then into an amplifier operating at a gain of 200 and finally into a 1024-channel analyzer. The analyzer records the data both in time (to identify the energy of the resonance level) and in pulse height (to determine the γ-ray energy). By operating the dynodes at 50 v/stage, the drifts in gain are less than 1% in 24 hours. The resolution is approximately 4–5% for the 4.95-Mev neutron capture γ ray from carbon. The peak to valley ratio for Cs^{137} γ rays is approximately 40:1. At present the apparatus is used to measure the energy of ground state capture γ rays. In a typical example, Pt^{196}, the ground state transition of 8 Mev occurs about 1% of the

time and the resolution is about 4%. Thirty percent of the 8-Mev γ rays interact in the crystals but only 10% of these appear in the photopeak.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

A8. Spin States for Low-Energy Neutron Resonances in Pt^{195}.† J. A. HARVEY, *Oak Ridge National Laboratory.*—Measurements have been made of the number of neutrons scattered as a function of neutron energy from thin foils of platinum in the energy range from 5 to 180 ev with the high-intensity fast chopper time-of-flight neutron spectrometer. Transmission measurements have also been made with the same foils (0.001 in., 0.004 in., and 0.014 in. thick) with the same energy resolution (0.07 μsec/m). From these measurements the ratio of Γ_n to Γ for the resonances can be determined after correcting for the self-absorption of the scattered neutrons. When the ratio of Γ_n to Γ for the various resonances is combined with thick and thin sample total cross-section measurements, the spins of the states in Pt^{196} corresponding to the resonances in Pt^{195} can be obtained. A preliminary analysis of the data, applying an approximate correction for the self-absorption of the scattered neutrons in getting out of the foil, indicates that the states corresponding to the resonances at 11.9, 19.4, 67.6, 113, 122, 141, and 151 ev have spin one and the state corresponding to the resonance at 155 ev may have spin zero. Measurements will be made with higher energy neutrons to extend the assignments to higher energy resonances.

† Work performed under the auspices of the U. S. Atomic Energy Commission.

A9. Radiation Widths Measured with the Nevis Slow Neutron Velocity Selector.* J. L. ROSEN, S. DESJARDINS, W. W. HAVENS, JR., AND J. RAINWATER, *Columbia University.*—Capture γ-ray self-indication measurements have been made on As, Br, I, Th, Nb, and Au. These have been supplemented by transmission measurements using our new B^{10}-NaI detector system. Analysis, now under way, can probably be made for energies and Γ_n values for most levels up to an energy of 1000 to 2000 ev. Γ_γ and g values are obtained in many cases. The following radiation widths in mv have been measured in As and Br. Resonance energies in ev are indicated in parentheses: As-330±60 (253), 300±35 (319), 340±50 (326.7), 345±100 (455), 290±30 (534), 340±70 (665), 630 ±60 (736), 300±100 (896). Br-280±40 (35.8), 423±40 (53.7), 252±25 (101.2), 344±40 (135.7), 450±90 (189.3), 326±130 (204.9), 620±60 (238.3), 400±120 (294.0), 425 ±45 (318.5), 368±74 (394.5). It should be noted that many of the values correspond to levels with large scattering widths and that in these cases the radiation width values are intimately related to the spin values assigned to the resonance. Methods of analysis and interpretation will be discussed.

* Supported by the U. S. Atomic Energy Commission and the Office of Naval Research.

A10. Radiation Widths in Sb and Hg.* H. H. BOLOTIN, R. E. CHRIEN, AND A. P. JAIN,† *Brookhaven National Laboratory.*—Neutron transmission measurements are sufficient for the determination of radiation widths for levels in the compound nucleus near the neutron binding energy, provided that $\Gamma \gg \Gamma_n$ for these levels. Such measurements have, in general, shown that radiation widths are remarkably constant from level to level in the same nucleus. Major exceptions to this rule have been reported in the cases of Sb^{121} [1] and Hg^{201}.[2] The BNL "fast chopper" has been used to re-examine these interesting cases. Conventional area analysis of transmission dips is used with a least squares analysis to find a Γ consistent with the results from a wide range of sample thicknesses. The radiation widths are then obtained by using $\Gamma_\gamma = \Gamma - 2g\Gamma_n$. For Sb^{121}, our results show little variation in Γ_γ, with Γ_γ =90±4, 88±10, and 89±10 mv for the 6.23-, 15.4-, and 29.7-ev levels, respectively. Results for the 23.3- and 91.1-ev levels in Hg^{198} are $\Gamma_\gamma = 130 \pm 14$ and 174 ± 23 mv, respectively; $\Gamma_\gamma = 376 \pm 95$ mv for the 131-ev level in Hg^{199}; in Hg^{201}, $\Gamma_\gamma = 241 \pm 36$ and 470 ± 70 mv for the 43.3- and 71.8-ev resonances, respectively. The mercury results agree with the Argonne results.[3]

* Work performed under the auspices of the U. S. Atomic Energy Commission.
† Student visitor from Cornell.
[1] A. Stolovy and J. A. Harvey, Phys. Rev. **108**, 353 (1957).
[2] R. T. Carpenter and L. M. Bollinger, Bull. Am. Phys. Soc. Ser. II, **4**, 271 (1959).

A11. Gamma Rays in Resonance Capture Theory.* G. BREIT, *Yale University.*—The discussion of the effect of gamma-ray emission in Vol. 41 of the *Encyclopedia of Physics* (pp. 64–73) will be supplemented in that its applicability to arbitrary multipolarity will be elucidated making use of the correspondence to classical electrodynamics equations. A combined treatment employing the Wigner $\mathfrak{R}$-matrix for particles and the method mentioned for gamma rays will be discussed and its relation to a combined $\mathfrak{R}$-matrix treatment of the whole system will be mentioned.

* This research was supported by the U. S. Atomic Energy Commission.

A12. Fluctuations in the Total Radiation Width of Hg^{201}.* R. T. CARPENTER AND L. M. BOLLINGER, *Argonne National Laboratory.*—The Argonne fast chopper has been used to investigate the large differences in the radiation widths reported[1] for the neutron resonances at 43, 71, and 210 ev in Hg^{201}. Additional transmission measurements were made on the 71-ev resonance using a very thick sample. The new result obtained for the radiation width is $\Gamma_\gamma = 460 \pm 60$ mv. The radiation width obtained for the 43-ev resonance is 290±13 mv. In an effort to find some reason for this large difference, measurements were made on the γ-ray spectra following capture in the resonances at 43, 71, and 210 ev. Gross fluctuations in the intensities of the high energy lines are observed. Moderately strong ground state and first excited state transitions are observed in the 210-ev spectrum. A very strong (~22 photons per 100 captures) first excited state transition is observed in the 71-ev spectrum. Both of these transitions are almost entirely absent from the 43-ev spectrum. The high energy transitions are also stronger for the 71- and 210-ev levels than the 43-ev level. In view of these findings the fluctuations in the total radiation widths appear quite reasonable.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] R. T. Carpenter and L. M. Bollinger, Bull. Am. Phys. Soc. Ser. II, **4**, 271 (1959).

B2. Radiative Capture of Fast Neutrons.* B. C. DIVEN AND JAMES TERRELL, *Los Alamos Scientific Laboratory.*—The technique of measurement of radiative capture cross sections by detection of the capture gamma rays will be described. The method is applicable to the measurement of capture cross sections for nearly all nuclides and can be used with neutrons of any energy from the thermal region to a few Mev. A pulsed and collimated neutron beam is passed through the capturing sample at the center of a large liquid scintillator. Capture is detected by counting the capture gamma radiation in the scintillator in coincidence with the pulsed beam. The liquid scintillator is a cylinder approximately 1 m in diam and length, with an axial cylindrical opening 7 cm in diam. The neutron beam passes along the axial opening and through the samples at its center. The accuracy so far achieved is about ±7% or ±1 mb, whichever is larger. The energy range which has been covered is 150 kev to 1 Mev. Cross sections of 28 elements will be presented.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

B3. Absolute Neutron Absorption Cross Sections at 24 kev.* H. W. SCHMITT, C. W. COOK,† AND J. H. GIBBONS, *Oak Ridge National Laboratory.*—Absolute neutron absorption cross sections have been measured for a number of elements at 24 kev using a spherical shell transmission measurement. Neutrons were obtained from a source consisting of a solid antimony sphere encased in a thin (0.030 in.) spherical beryllium shell. Average neutron energy from this source was 24±2 kev; the spread was 3-kev full width. The neutron detector was a modified long counter, shielded from source γ rays by lead; this entire assembly was positioned at a distance from the source large compared to the sample shell diameters. A serious attenpt was made to maintain "good geometry" in these measurements and corrections for finite source size, finite source-to-detector distance, etc., were minimized, evaluated, and taken into account. Multiple scattering in the sample shells was evaluated according to the method of Bethe, Beyster, and Carter.[1] The effect of resonance self-shielding was evaluated according to a method of Dresner.[2] Absorption cross sections for elements measured thus far are as follows: silver, 1210±65 mb; cadmium, 510±90 mb; indium, 820±60 mb; antimony, 570±35 mb; iodine, 845±90 mb; gold 590±65 mb; and lead, 3±10 mb.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] Bethe, Beyster, and Carter, J. Nuclear Energy **3**, 207, 273 (1956); **4**, 3, 147 (1957).
[2] Dresner, Oak Ridge National Laboratory Report ORNL-2659, 1959 (unpublished).

B4. Radiative Capture Measurements for kev Neutrons. I. Experimental Techniques and Gamma Spectrum Measurements.* J. H. NEILER, J. H. GIBBONS, R. L. MACKLIN, AND P. D. MILLER, *Oak Ridge National Laboratory.*—This work is based upon two uses of a pulsed beam accelerator and gamma total absorption detector. The sensitivity of the first method, where the neutron energy spread is determined by the reaction [lithium or tritium (p,n)] target thickness and beam pulsing provides only background discrimination, has been increased by the self collimation effect at the reaction threshold. When the second method is used the beam pulsing also provides time-of-flight measurement of the neutron energy. Using thick lithium or tritium targets and a massive paraffin-lithium-lead collimator it is then possible to determine the cross section as a continuous function of neutron energy. In all cases the value of the cross section is dependent upon knowledge of the efficiency of capture gamma detection for the various elements and neutron energies. Utilization of the pulsed beam methods has permitted measurement of the pulse spectra resulting from capture of neutrons of several energies (primarily 29 and 63 kev) in many of the elements studied. These spectra, combined with estimates of minimum gamma multiplicities and Monte Carlo calculations of the spectra to be expected for simple multiple gamma cascades establish the uncertainty limits of the detector efficiency.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

B5. Radiative Capture Measurements for kev Neutrons. II. Neutron Flux Measurements and the Cross Section of Indium.* P. D. MILLER, J. H. NEILER, J. H. GIBBONS, AND R. L. MACKLIN, *Oak Ridge National Laboratory.*—Since all the capture cross sections have been measured relative to indium, considerable effort has been expended in accurately determining the shape and magnitude of the indium cross section. The capture cross section of indium has been measured relative to the absorption cross section of U^{235} using $Li^7(p,n)Be^7$ neutrons from a thin lithium target in the energy range from 10 to 400 kev. Neutron energies were determined from the incident proton energies, and the neutron flight times were used to distinguish capture events from background. In a second experiment, the cross section of indium as a function of energy has been measured relative to the known 1/v shape of the $B^{10}(n,\alpha\gamma)Li^7$ cross section in the energy range 10 to 175 kev using $Li^7(p,n)Be^7$ and $T(p,n)He^3$ neutrons from thick targets and using velocity selection to determine the neutron energies. The absolute value of the cross section was obtained by normalization to the thin target results compared to σ_a of U^{235}. In a third measurement, an indium foil was calibrated by activation with 29 kev, $Li^7(p,n)Be^7$ forward threshold neutrons, where the neutron flux was determined with a graphite sphere detector. This calibrated foil was then activated using 29-kev neutrons.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

B6. Radiative Capture Measurements for kev Neutrons. III. Cross Section Results.* R. L. MACKLIN, P. D. MILLER, J. H. NEILER, AND J. H. GIBBONS, *Oak Ridge National Laboratory.*—Cross sections at neutron energies of 29±17 kev and 63±40 kev (full width at half maximum) have been measured for about 40 elements since these two energies are particularly appropriate for comparison with various theories of nucleogenesis. Also, these numbers provide a basis for normalization of relative cross-section measurements. Cross sections for 167±2 kev neutrons have been determined for 14 elements in order to provide more direct comparisons with results of other workers. Cross-section measurements as a continuous function of neutron energy from about 10 to about 175 kev have been completed for about 25 elements. A few lighter elements were studied where individual resonances were observed. Radiative widths of a few selected resonances have been determined. For heavier elements, where only average cross section is observed, the cross section generally follows a shape of roughly $\sigma_c \propto E_n^{-0.6}$, but deviations from a pure exponential behavior are evident in more than one case.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

B7. Background Reduction in Neutron Capture Gamma-Ray Measurements.* L. CRANBERG AND GEORGE I. BELL, *Los Alamos Scientific Laboratory.*—To improve the sensitivity and accuracy of neutron capture gamma-ray measurements by use of a large scintillator,[1] it is essential to reduce the background due to capture in the scintillator of neutrons scattered by the sample. It is proposed that this be done by interposing between the scatterer and the detector a material which has high stopping power for neutrons, yet high transmission for gamma rays. Machine calculations have been made based on the use of Li^6H in cylindrical geometry, assuming various neutron energies and thicknesses of absorber, and taking account of reflection of neutrons by the scintillator back into the absorber. Detailed results will be given. It is shown that a factor of ten reduction in background can be accomplished over a significant range of neutron energy at a cost of less than 15% in gamma-ray efficiency, with thicknesses of material in the neighborhood of 5 cm.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] Neiler, Macklin, Gibbons, and Miller, Bull. Am. Phys. Soc. Ser. II, **4**, 43 (1959). Diven, Terrell, and Hemmindinger, Phys. Rev. **109**, 144 (1958).

B8. Neutron Capture Measurements with the ORNL Fast Chopper.* ROBERT C. BLOCK, *Oak Ridge National Laboratory.*—A liquid scintillator tank has been recently installed at an 11.5-m flight station of the ORNL fast chopper time-of-flight neutron spectrometer. The scintillation tank is 28 in. in diam. Four 5 in. photomultipliers are used for the light collection. A 4 in. thick lead shield is used to reduce background. This system has been used to measure the capture cross section of a given nuclide in the 10- to 20 000-ev region with a resolution of 0.2 μsec/m. The "averaged-over-resonances" capture cross sections of natural In, Ag, W, and Au have been obtained in the 0.2- to 17-kev energy range

and agree to within 10% with the results of Neiler *et al.*[1] in the overlap energy range from ~8 to 20 kev. In the energy range below ~150 ev many resonances have been resolved and these capture data and other transmission measurements data have been analyzed to obtain Γ_γ/Γ for each resonance. The following assignments of Γ_γ/Γ have thus far been made: 0.61 ± 0.10, 0.22 ± 0.04, 0.74 ± 0.12, and 0.29 ± 0.04 for the resonances, respectively, at 102 and 115 ev in W and at 67 and 96 ev in Pt.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] Papers B4, B5, and B6 (this Meeting).

B9. Energy Dependence of Fast-Neutron Activation Cross Sections.* M. G. SILBERT,† A. E. JOHNSRUD,‡ AND H. H. BARSCHALL, *University of Wisconsin.*—Fast-neutron capture cross sections of 24 nuclides ranging from $A=51$ to $A=197$ have been measured by an activation method in the neutron energy region from 0.15 to 6.2 Mev. Preliminary results of these measurements have been reported previously.[1] The neutron energy spreads were of the order of 0.1 Mev so that cross sections averaged over many energy levels of the compound nucleus were measured. Activities induced in samples by fast and thermal neutrons were compared. The relative neutron fluxes in the fast- and thermal-neutron activations were determined with a U^{235} fission counter. A knowledge of the energy dependence of the U^{235} fission cross section and of the thermal-neutron activation cross sections allows calculation of the fast-neutron activation cross sections. In general, the neutron capture cross sections were observed to decrease monotonically in the energy region investigated. In several cases, notably In^{115}, Ba^{138}, Sm^{154}, and Dy^{164}, the cross sections exhibited a plateau or a maximum.

* Work supported by the U. S. Atomic Energy Commission and by the Graduate School from funds supplied by the Wisconsin Alumni Research Foundation.
† Present address: Los Alamos Scientific Laboratory.
‡ Present address: Hughes Aircraft Company.
[1] Austin, Silbert, Fossan, and Wilson, Bull. Am. Phys. Soc. Ser. II, **4**, 43 (1959).

B10. Neutron Activation Cross Sections for Hf^{180}, Ta^{181}, W^{186}, Au^{197}, and Th^{232}.* J. A. MISKEL, K. V. MARSH, M. LINDNER, AND R. J. NAGLE, *University of California, Livermore.*—The (n,γ) activation cross sections for the foregoing nuclides have been measured as a function of neutron energy for neutron energies between 31 kev and 6 Mev. The neutron induced activities were measured with a gamma-ray scintillation counter; absolute disintegration rates were determined by direct comparison of the scintillation counter with a 4π proportional counter. U^{235} or U^{238} fission counters were used to determine the neutron flux. The curves for the energy dependence of the cross sections do not exhibit a simple $1/V$ or $1/E$ dependence.

* This work was performed under the auspices of the U. S. Atomic Energy Commission.

B11. Prediction of Neutron Capture Cross Sections.* JAMES TERRELL AND B. C. DIVEN, *Los Alamos Scientific Laboratory.*—The average neutron capture cross section is given by resonance theory as $\langle\sigma(n,\gamma)\rangle=2\pi^2\lambda^2\langle g\Gamma_n\Gamma_\gamma/\Gamma\rangle\omega\omega_s(E)$ for well separated resonances, plus similar terms for $l>0$. In this equation $\omega_s(E)$ is the level density at an excitation energy E, for s-wave resonances, and the other symbols have their usual meanings. For neutron energies of a few hundred kev $\Gamma_n>\Gamma_\gamma$ for $l=0$ and $l=1$, and $\langle g\Gamma_n\Gamma\gamma/\Gamma\rangle\cong\langle g\Gamma_\gamma\rangle$. Because Γ_γ is not strongly dependent on the target nuclide, being of the order of 0.1 ev for most cases, the value of $\langle\sigma(n,\gamma)\rangle$ is primarily dependent on the level density. According to evaporation theory $\omega(E)\cong\text{const}\exp[(4aE)^{\frac{1}{2}}]$, in which $a=E/T^2\cong 2AMr_0^2\hbar^{-2}(\pi/3)^{4/3}\cong 0.10A$ Mev^{-1}, for A nucleons of mass M contained in a spherical volume of radius $r_0A^{1/3}$. Thus the capture cross section should vary nearly exponentially with $(AE)^{1/2}$, for a given neutron energy. It is found that measured neutron capture cross sections at 400 kev and lower energies are very well correlated by these ideas. It is necessary that the excitation E be measured not from the ground state but from a reference mass surface, such as Cameron's which does not include even-odd factors or shell effects. Apparently neutron capture cross sections can be predicted in this way.

* Work performed under the auspices of the U. S. Atomic Energy Commission.

B12. Spin-Orbit Coupling and Neutron Capture.* L. W. WESTON, E. G. BILPUCH, K. K. SETH, AND H. W. NEWSON, *Duke University.*—Absorption cross-section curves have been measured by the activation method for a number of elements near mass number 90 over the energy region 3 kev to 250 kev. We have fitted our data by the incoherent addition of the partial cross sections due to s- and p-wave neutrons. When the s-wave parameters $\bar{\Gamma}_n^0$, Γ_γ, and D are known the average s-wave absorption cross section can be computed as a function of energy. Analysis of our data shows that the total p-wave contribution above about 10 kev becomes comparable to or greater than the s-wave contribution. The p-wave cross section decreases as $1/E$ at high energies but rises as $E^{\frac{1}{2}}$ at low energies (where it is nearly independent of Γ_γ) under the influence of the p-wave penetration factor. A calculated fit to the p-wave partial cross section at low energies yields an estimate of the p-wave strength function. For nuclei near $A=90$, the FPW model predicts a maximum in the p-wave strength function. Combining total[1,2] and capture cross-section data for this region we find a double peak. We attribute this splitting of the maximum to spin-orbit coupling.

* This work was supported by the U. S. Atomic Energy Commission.
[1] Saplakoglu, Bollinger, and Coté, Phys. Rev. **109**, 1258 (1958).
[2] Newson, Block, Nichols, Taylor, Furr, and Merzbacher, Ann. phys. (October, 1959).

B13. Parity and Neutron Capture.* H. W. NEWSON, E. G. BILPUCH, AND L. W. WESTON, *Duke University.*—Recent calculations[1] have shown that the shell model is a useful guide for predicting relative level densities for heavy compound nuclei if we count all the possible configurations of 0+ neutron and proton pairs in unfilled shells, and assume a spherically symmetric potential. If we make a similar estimate of the relative spacings for s- and p-wave resonances above $A=190$ we predict a considerably greater level density for the latter, since there are relatively few ways to change the parity of the entering neutron if the target is even-even. If there is an odd proton in the target nucleus, this effect will be much less important since the parity of the odd proton can change readily. On the basis of this model we can understand the relative s- and p-wave contributions[2] to the capture cross sections of U^{238}, Pt^{198}, and Au^{197} and the s- and p-wave resonance spacings (as determined from total cross sections) in the even-even lead isotopes.

* This work is supported by the U. S. Atomic Energy Commission.
[1] H. W. Newson and M. M. Duncan, Phys. Rev. Letters **3**, 45 (1959).
[2] H. W. Newson and E. G. Bilpuch, Bull. Am. Phys. Soc. Ser. II, **2**, 218 (1957).

B14. Resonance Parameter Analysis using Fast Neutron Capture Cross Section Data.* P. A. MOLDAUER, *Argonne National Laboratory.*—The GEORGE computer has been used to analyze reported measurements[1] of the radiative capture cross sections of neutrons with energies between a few kv and a few Mev for some fifteen nuclides for which also reliable average s-wave neutron resonance parameters are available. The results indicate p-wave neutron strength functions consistent with the predictions of the complex well model, though there is some indication of a broadening or splitting of the peak at $A=100$. Some support for a complex well model behavior of the d-wave strength functions is

also obtained. Assuming a two Fermi gas model for the level spacing the results are consistent with a single particle level spacing which varies gradually from about 200 kev at $A=50$ to 50 kev at $A=250$, and with angular momentum level sequences having maximum level density at $J=4\hbar$ or higher.

* Performed under the auspices of the U. S. Atomic Energy Commission.
[1] Macklin, Lazar, and Lyon, Phys. Rev. **107**, 504 (1957); **114**, 1619 (1959); Barshall, Johnsrud and Silbert, Bull. Am. Phys. Soc. Ser. II, **4**, 321 (1959); **3**, 165 (1959); **3**, 364 (1958); B. C. Diven, Second United Nations International Conference on *Peaceful Uses of Atomic Energy*, P/667 (see also AEC report WASH-1013); M. Lindner and J. A. Miskel, AEC report WASH-1018 (unpublished); S. J. Bame, Jr., and R. L. Cubitt, Phys. Rev. **113**, 256 (1959); Hanna and Rose, J. Nuclear Energy **8**, 197 (1959); E. G. Bilpuch (private communication).

C3. Light Element Formation During Early Stages of the Expanding Universe.* James W. Follin, Jr., *The Johns Hopkins University*, Ralph A. Alpher, *General Electric Corporation*, and Robert C. Herman, *General Motors Research Laboratory*.—We have extended our earlier work[1] and have made detailed calculations of the generation of light elements by thermonuclear reactions in the initial stages of the expanding universe. Preliminary results indicate that sufficient D, He, Li, Be, and B were formed to explain terrestrial abundances. Very few heavier elements were formed; these were presumably generated in stellar interiors as demonstrated by Fowler[2] *et al.* This work complements the stellar theories since light elements cannot be made in stars. Results will be presented giving the composition and density of the material from which galaxies, and the earliest stars, condensed.

* This work was partially supported by the U. S. Bureau of Ordnance, Department of the Navy.
[1] Alpher, Follin, and Herman, Phys. Rev. **92**, 1347 (1953).
[2] Burbidge, Burbidge, Fowler, and Hoyle, Revs. Modern Phys. **29**, 547 (1957).

D3. Thermal Neutron Capture and the (d,p) Reaction.* Charles K. Bockelman, *Yale University*.—The suggestion[1] that the similarity between (d,p) and (n,γ) spectra may be understood in terms of the target as a unique parent state is applied in detail. An examination of the available data shows six nuclei for which the assumption of a unique parent state appears to be satisfied, and four ambiguous situations. Clear disagreement is found for three nuclei. In order to inquire further into the circumstances responsible for the cases of agreement, the cross section for direct neutron capture with the emission of an electric dipole γ ray is evaluated with the help of the optical model. Comparison with experiment shows agreement only for the target nucleus Mg^{24}. However, (d,p) reduced widths needed to evaluate the direct cross sections do not exist in the region where the optical model predicts the largest effects. These maxima occur at the same A for which the s-wave strength function is greatest. Measured (n,γ) cross sections for $E1$ transitions are in many cases compatible with the direct process.

* Work performed at the Institute for Theoretical Physics, Copenhagen, Denmark.
[1] A. M. Lane and D. H. Wilkinson, Phys. Rev. **97**, 1199 (1955).

D4. Binding Energy of the Deuteron.* J. Monahan, S. Raboy, and C. C. Trail, *Argonne National Laboratory*.—The gamma rays resulting from the radiative capture of neutrons by hydrogen have been studied with an anti-coincidence scintillation spectrometer.[1] A Pu-Be neutron source is immersed in a barrel of distilled water and the energy of the radiation is measured with respect to the 1368.0- and 2753.5-kev lines of Na^{24} and the 661.6-kev line of Cs^{137}. Further measurements are in progress. Methods of calculations and experiments to eliminate systematic errors will be described.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] C. C. Trail and S. Raboy, Rev. Sci. Instr. **30**, 425 (1959).

D5. Gamma-Gamma Coincidences in Hg^{199} and Sm^{149} Neutron Capture Gamma Rays using a Sum-Coincidence Method. J. F. Vervier, *Centre d'Etude l'Energie Nucleaire* (introduced by M. Neve de Mevergnies).—Double cascades starting from the capturing level and going to the ground state of Hg^{200} have been studied in Hg^{199} neutron capture γ rays using a sum-coincidence method introduced by Hoogenboom.[1] The following cascades have been found (the relative intensities, in arbitrary units, are in parentheses): 6.44−1.59 Mev (8.55±0.21), 5.44−2.64 Mev (6.18±0.18), and 4.8−3.25 Mev (16.94±0.29). Comparison with previous measurements[2,3] shows that the first cascade is composed of two unresolved cascades: 6.44−1.59 Mev and 6.31−1.73 Mev; relative intensities are in agreement with Segel's results[2] and rule out a 4.94−3.14 Mev cascade with the intensity proposed by Adyasevich *et al.*[3] The same method has been used to detect the 0.440−0.337 Mev cascade starting from the 0.77 Mev-sec excited state and going to the ground state of Sm^{150}.

[1] A. M. Hoogenboom, Nuclear Instr. **3**, 57 (1958).
[2] R. E. Segel, Phys. Rev. **111**, 1620 (1958).
[3] Adyasevich, Groshev, and Demidov, *Proceedings of the Conference of the Academy of Sciences of the U.S.S.R. on the Peaceful Uses of Atomic Energy, Moscow, July, 1955*; Phys.-Math. Sci. (English translation, p. 195).

D6. Gamma Radiation Following Thermal Neutron Capture in Gd^{155}. J. W. Knowles, G. A. Bartholomew, and P. J. Campion, *Atomic Energy of Canada Limited*.—The γ rays of Gd^{156} following neutron capture in the separated isotope Gd^{155} have been studied from 0.65 to 3.0 Mev with a flat crystal diffraction spectrometer, resolution about 0.5%, and for specific measurements 0.18% and from 3.0 to 9.0 Mev with a pair spectrometer, resolution 1.0%. About 80 γ rays have been resolved. A number of these which includes most of the more intense γ rays are assigned to a level scheme originally proposed by Ofer.[1] The energies of these γ rays are 88.96±0.01, 199.3±0.1, 262.8±0.2, 296.8±0.2, 356.9±0.2, 533.7±0.4, 866.2±0.6, 960.4±1.5, 1065.6±1.0, 1154.5±0.5, 1159.6±0.5, 1223±1.0, and 1422±1.0 kev. The 88.92-, 199.3-, and 296.8-kev γ rays can be interpreted as transitions in the $K=0$ ground state rotational band with levels at 88.92(2+), 288.2(4+), and 585.0(6+) kev. Values of the moment of inertia parameter $\hbar^2/2I=14.99$ kev and the rotation vibration parameter $B=0.0291$ kev are calculated from the levels at 88.96 and 288.2 kev. The precise measurement of γ rays of energy 1154.5, 1065.6, and 866.2 kev implies a level at 1154.5 kev and of the 960.4- and 1159.6-kev γ rays a level at 1248.6 kev; further γ rays at 262.8, 356.9, 1223, and 1422 kev imply a level at 1511.4 kev.

[1] S. Ofer, Bull. Am. Phys. Soc. Ser. II, **3**, 357 (1958).

D7. Two-Step Ground State Cascades in Cl^{36}. J. E. Draper and A. A. Fleischer, *Yale University*.—The thermal neutron capture γ rays of the product nucleus Cl^{36} are being investigated to determine the relative intensities of all two-step cascades starting from the capturing level and terminating at the ground state. The sum-coincidence selection of pulses is employed whereby pulses from each of the two NaI(Tl) crystals must be in coincidence, and the sum of their amplitudes must be equivalent to the neutron binding energy of Cl^{36}. The scintillators are 5-in. diam by 4-in. The neutron source is the 6-Mev electron linear accelerator. When the relative cascade intensity is divided by the intensity (Groshev *et al.*) of the initial γ ray the result is the branching ratio to ground from the intermediate state. The results for the branching ratio are listed after the level energy: 0.79 Mev (≡1), 1.16 Mev (0.99±0.2), 1.60 Mev (1.2±0.5), 1.95 Mev (1.1±0.3), 2.47 Mev (<0.1), 2.68 Mev (∼1), 2.87 Mev (0.9±0.2), 3.06 Mev (1.2±0.6), 3.34 Mev (−), and 3.58 Mev (<0.1). Note that the two initial γ rays with the largest reduced widths terminate on levels (near 2.47 and 3.58 Mev)

with the smallest branching ratio to ground. Similar results were found by Segel.

D8. Gamma-Ray Energy Measurements with a Compton Spectrometer.* H. T. Motz, R. E. Carter, and P. C. Fisher,† *Los Alamos Scientific Laboratory.*—The OWR Compton spectrometer[1] is being tested for accuracy of γ-ray energy measurements. Energies are computed on an IBM 704 for each of four to eight coincidence channels at a given magnetic field setting and yields combined into a composite yield. A full line width at half-maximum of 15 to 25 kev for γ rays of 1 to 8 Mev is obtained using a 12.4 mg/cm² Be converter 3 mm wide and 50 mm high. The prompt γ ray from $H^1(n\gamma)H^2$ has been measured relative to the 2753.3 kev Mg^{24} line[2] for 12 paired runs from a NaOH source and for two paired runs from a CH_2 source. The spread in the fourteen values is 1.8 kev, and an average value for the binding energy of the deuteron of 2224.3 kev is found after adding 1.3 kev for Doppler shift. The present measurements indicate that an over-all error to the binding energy of ± 1 kev should be obtained. However, checks for possible systematic errors remain to be made, and the present result should be considered as preliminary.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
† Present address: Lockheed Aircraft Corporation.
[1] Motz, Carter, and Fisher, Bull. Am. Phys. Soc. Ser. II, **4**, 246 (1959).
[2] A. Hedgran and D. E. Lind, Arkiv Fysik **5**, 177 (1952), as quoted by T. R. Gerholm (private communication, September, 1959).

D9. Capture Gamma-Ray Spectrum from Titanium.* R. E. Carter, H. T. Motz, P. C. Fisher,† and W. D. Barfield,‡ *Los Alamos Scientific Laboratory.*—The γ-ray spectrum from natural titanium placed in the thermal column of the OWR has been measured from 1.3 to 7.6 Mev. Energies were determined by using a $\sqrt{2}\pi$ magnetic spectrometer to obtain coincidences between a Compton electron and the back-scattered γ-ray.[1] The spectrometer was operated as either a six or eight channel coincidence system. Two of the 35 lines whose energies were obtained reliably were from the carbon of the thermal column, and seven additional weaker lines were observed. The energy calibration is the 2753.3 ± 1 kev line from Mg^{24}, and on this basis the energies of the Ti lines above 3 Mev are found to be about two parts in 10^3 higher than reported by Knowles *et al.*[2] An independent and consistent energy discrepancy with one of the Ti lines is obtained from the $C^{12}(n,\gamma)C^{13}$ ground-state line which forms a close doublet. Further measurements are in progress.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
† Present address: Lockheed Aircraft Corporation.
‡ Temporary address: Rice Institute.
[1] Motz, Carter, and Fisher, Bull. Am. Phys. Soc. Ser. II, **4**, 246 (1959).
[2] Knowles, Manning, Bartholomew, and Campion, Phys. Rev. **114**, 1065 (1959).

D10. Coincidence Studies of Chromium Capture Gamma Rays.* John D. Fox, Walter R. Kane, and Walter Kley, *Brookhaven National Laboratory.*—Gamma rays from a natural chromium sample placed in a thermal neutron beam at the Brookhaven reactor are detected by a three-crystal pair spectrometer and a 3×3 in. NaI crystal simultaneously. Coincidences are recorded on a two dimensional 2048 (32×64) channel kicksorter.[1] The following cascades are observed: 8.9–0.84, 8.5–0.77, 7.4–0.56, 7.0–1.82–0.84, 6.7–2.28–0.84, 5.6–2.35 Mev. There are no strong coincidences at 7.9 Mev. These data and the results of Kinsey and Bartholomew[2] lead to the following isotopic assignments for gamma transitions (levels excited in parentheses): Cr^{51}-8.499 (0.78); Cr^{52}-7.929 (0), 7.364 (0.56), 5.61 (2.32); Cr^{54}-8.881 (0.84), 7.097 (2.62), 6.644 (3.07). In Cr^{52} deexcitation of the 2.32-Mev level proceeds chiefly via a direct transition to the ground state. In Cr^{54} deexcitation of both the 2.62- and 3.07-Mev levels proceeds chiefly via cascade transitions to the first excited state. Thus the latter level is not the primary source of the 3-Mev capture gamma rays reported for chromium.

* Work performed under the auspices of the U. S. Atomic Energy Commission.
[1] R. L. Chase, Brookhaven National Laboratory Report No. 3838 (1958).
[2] B. B. Kinsey and G. A. Bartholomew, Phys. Rev. **89**, 375 (1953).

D11. Nuclear Reactor As a Source of Intense and Discrete Gamma Rays up to 11 Mev. L. Jarczyk, H. E. Knoepfel, J. Lang, and W. Wölfli, *Federal Institute of Technology, Zurich.*—As sources of discrete γ rays above 3 Mev, generally only proton capture reactions are mentioned.[1] A comparison with the neutron capture γ rays shows that for an appropriate experimental arrangement this gamma source might be in many regards superior. The obtainable intensities might be some order of magnitude higher, an advantage which in the field of applied gamma research is of importance. Some simple (n,γ)-spectra contain a choice of intense and resolved gamma lines, e.g. (energy in Mev): 4.1 (Bi), 4.9 (C), 5.4 (S), 6.7 (Ti), 7.4 (Pb), 7.7 (Al), 9.0 (Ni), 10.8 (N). The intensities measured at the end of the four-meter tangential beam hole of the Swiss pool-type reactor SAPHIR for 500-g targets and $\Phi_{th} = 5\times10^{12}$ cm^{-2} sec^{-1} are (Quanta cm^{-2} sec^{-1}): 7×10^4 (C), 2×10^7 (Ti), 3×10^5 (Pb), 5×10^6 (Fe), 2×10^5 (N). An accelerator with 1-ma proton current gives at one meter distance at best: 1×10^4 [$F^{19}(p,\alpha\gamma)$, 6.1 Mev], 1×10^3 [$Li^7(p,\gamma)$, 17.6]. The reactor as a gamma source for the mentioned energy range is therefore equivalent to an accelerator with even more than 1-amp proton current.

[1] *Encyclopedia of Physics*, edited by S. Flügge, (Springer-Verlag, Berlin, 1958), Vol. XLII, p. 311.

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